

STATA LONGITUDINAL-DATA/PANEL-DATA REFERENCE MANUAL RELEASE 13



A Stata Press Publication
StataCorp LP
College Station, Texas



Copyright © 1985–2013 StataCorp LP
All rights reserved
Version 13

Published by Stata Press, 4905 Lakeway Drive, College Station, Texas 77845
Typeset in \TeX

ISBN-10: 1-59718-118-8
ISBN-13: 978-1-59718-118-1

This manual is protected by copyright. All rights are reserved. No part of this manual may be reproduced, stored in a retrieval system, or transcribed, in any form or by any means—electronic, mechanical, photocopy, recording, or otherwise—without the prior written permission of StataCorp LP unless permitted subject to the terms and conditions of a license granted to you by StataCorp LP to use the software and documentation. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted by this document.

StataCorp provides this manual “as is” without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. StataCorp may make improvements and/or changes in the product(s) and the program(s) described in this manual at any time and without notice.

The software described in this manual is furnished under a license agreement or nondisclosure agreement. The software may be copied only in accordance with the terms of the agreement. It is against the law to copy the software onto DVD, CD, disk, diskette, tape, or any other medium for any purpose other than backup or archival purposes.

The automobile dataset appearing on the accompanying media is Copyright © 1979 by Consumers Union of U.S., Inc., Yonkers, NY 10703-1057 and is reproduced by permission from CONSUMER REPORTS, April 1979.

Stata, **STATA** Stata Press, Mata, **MATA** and NetCourse are registered trademarks of StataCorp LP.

Stata and Stata Press are registered trademarks with the World Intellectual Property Organization of the United Nations. NetCourseNow is a trademark of StataCorp LP.

Other brand and product names are registered trademarks or trademarks of their respective companies.

For copyright information about the software, type `help copyright` within Stata.

The suggested citation for this software is

StataCorp. 2013. *Stata: Release 13*. Statistical Software. College Station, TX: StataCorp LP.

Contents

intro	Introduction to longitudinal-data/panel-data manual	1
xt	Introduction to xt commands	2
quadchk	Check sensitivity of quadrature approximation	10
vce_options	Variance estimators	20
xtabond	Arellano–Bond linear dynamic panel-data estimation	24
xtabond postestimation	Postestimation tools for xtabond	42
xtcloglog	Random-effects and population-averaged cloglog models	45
xtcloglog postestimation	Postestimation tools for xtcloglog	60
xtdata	Faster specification searches with xt data	63
xtdescribe	Describe pattern of xt data	70
xtdpd	Linear dynamic panel-data estimation	74
xtdpd postestimation	Postestimation tools for xtdpd	93
xtdpdsys	Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation	98
xtdpdsys postestimation	Postestimation tools for xtdpdsys	108
xtfrontier	Stochastic frontier models for panel data	112
xtfrontier postestimation	Postestimation tools for xtfrontier	124
xtgee	Fit population-averaged panel-data models by using GEE	127
xtgee postestimation	Postestimation tools for xtgee	146
xtgls	Fit panel-data models by using GLS	155
xtgls postestimation	Postestimation tools for xtgls	165
xhtaylor	Hausman–Taylor estimator for error-components models	167
xhtaylor postestimation	Postestimation tools for xhtaylor	180
xtintreg	Random-effects interval-data regression models	184
xtintreg postestimation	Postestimation tools for xtintreg	193
xtivreg	Instrumental variables and two-stage least squares for panel-data models	197
xtivreg postestimation	Postestimation tools for xtivreg	219
xtline	Panel-data line plots	221
xtlogit	Fixed-effects, random-effects, and population-averaged logit models	225
xtlogit postestimation	Postestimation tools for xtlogit	243
xtnbreg	Fixed-effects, random-effects, & population-averaged negative binomial models	247

<code>xtnbreg postestimation</code>	Postestimation tools for <code>xtnbreg</code>	260
<code>xtologit</code>	Random-effects ordered logistic models	263
<code>xtologit postestimation</code>	Postestimation tools for <code>xtologit</code>	272
<code>xtoprobit</code>	Random-effects ordered probit models	275
<code>xtoprobit postestimation</code>	Postestimation tools for <code>xtoprobit</code>	284
<code>xtpcse</code>	Linear regression with panel-corrected standard errors	287
<code>xtpcse postestimation</code>	Postestimation tools for <code>xtpcse</code>	298
<code>xtpoisson</code>	Fixed-effects, random-effects, and population-averaged Poisson models	300
<code>xtpoisson postestimation</code>	Postestimation tools for <code>xtpoisson</code>	323
<code>xtprobit</code>	Random-effects and population-averaged probit models	327
<code>xtprobit postestimation</code>	Postestimation tools for <code>xtprobit</code>	347
<code>xtrc</code>	Random-coefficients model	350
<code>xtrc postestimation</code>	Postestimation tools for <code>xtrc</code>	357
<code>xtreg</code>	Fixed-, between-, and random-effects and population-averaged linear models	359
<code>xtreg postestimation</code>	Postestimation tools for <code>xtreg</code>	388
<code>xtregar</code>	Fixed- and random-effects linear models with an AR(1) disturbance	395
<code>xtregar postestimation</code>	Postestimation tools for <code>xtregar</code>	410
<code>xtset</code>	Declare data to be panel data	412
<code>xtsum</code>	Summarize <code>xt</code> data	425
<code>xttab</code>	Tabulate <code>xt</code> data	427
<code>xttobit</code>	Random-effects tobit models	430
<code>xttobit postestimation</code>	Postestimation tools for <code>xttobit</code>	438
<code>xtunitroot</code>	Panel-data unit-root tests	440
Glossary		471
Subject and author index		475

Cross-referencing the documentation

When reading this manual, you will find references to other Stata manuals. For example,

[U] **26 Overview of Stata estimation commands**

[R] **regress**

[D] **reshape**

The first example is a reference to chapter 26, *Overview of Stata estimation commands*, in the *User's Guide*; the second is a reference to the **regress** entry in the *Base Reference Manual*; and the third is a reference to the **reshape** entry in the *Data Management Reference Manual*.

All the manuals in the Stata Documentation have a shorthand notation:

[GSM]	<i>Getting Started with Stata for Mac</i>
[GSU]	<i>Getting Started with Stata for Unix</i>
[GSW]	<i>Getting Started with Stata for Windows</i>
[U]	<i>Stata User's Guide</i>
[R]	<i>Stata Base Reference Manual</i>
[D]	<i>Stata Data Management Reference Manual</i>
[G]	<i>Stata Graphics Reference Manual</i>
[XT]	<i>Stata Longitudinal-Data/Panel-Data Reference Manual</i>
[ME]	<i>Stata Multilevel Mixed-Effects Reference Manual</i>
[MI]	<i>Stata Multiple-Imputation Reference Manual</i>
[MV]	<i>Stata Multivariate Statistics Reference Manual</i>
[PSS]	<i>Stata Power and Sample-Size Reference Manual</i>
[P]	<i>Stata Programming Reference Manual</i>
[SEM]	<i>Stata Structural Equation Modeling Reference Manual</i>
[SVY]	<i>Stata Survey Data Reference Manual</i>
[ST]	<i>Stata Survival Analysis and Epidemiological Tables Reference Manual</i>
[TS]	<i>Stata Time-Series Reference Manual</i>
[TE]	<i>Stata Treatment-Effects Reference Manual: Potential Outcomes/Counterfactual Outcomes</i>
[I]	<i>Stata Glossary and Index</i>
[M]	<i>Mata Reference Manual</i>

Title

intro — Introduction to longitudinal-data/panel-data manual

[Description](#)

[Remarks and examples](#)

[Also see](#)

Description

This entry describes this manual and what has changed since Stata 12.

Remarks and examples

This manual documents the `xt` commands and is referred to as `[XT]` in cross-references.

Following this entry, [\[XT\] `xt`](#) provides an overview of the `xt` commands. The other parts of this manual are arranged alphabetically. If you are new to Stata's `xt` commands, we recommend that you read the following sections first:

- [\[XT\] `xt`](#) Introduction to `xt` commands
- [\[XT\] `xtset`](#) Declare a dataset to be panel data
- [\[XT\] `xtreg`](#) Fixed-, between-, and random-effects, and population-averaged linear models

Stata is continually being updated, and Stata users are always writing new commands. To find out about the latest cross-sectional time-series features, type `search panel data` after installing the latest official updates; see [\[R\] `update`](#).

What's new

For a complete list of all the new features in Stata 13, see [\[U\] 1.3 What's new](#).

Also see

[\[U\] 1.3 What's new](#)

[\[R\] `intro`](#) — Introduction to base reference manual

Syntax

`xtcmd ...`

Description

The `xt` series of commands provides tools for analyzing panel data (also known as longitudinal data or in some disciplines as cross-sectional time series when there is an explicit time component). Panel datasets have the form \mathbf{x}_{it} , where \mathbf{x}_{it} is a vector of observations for unit i and time t . The particular commands (such as `xtdescribe`, `xtsum`, and `xtreg`) are documented in alphabetical order in the entries that follow this entry. If you do not know the name of the command you need, try browsing the second part of this description section, which organizes the `xt` commands by topic. The next section, [Remarks and examples](#), describes concepts that are common across commands.

The `xtset` command sets the panel variable and the time variable; see [\[XT\] xtset](#). Most `xt` commands require that the panel variable be specified, and some require that the time variable also be specified. Once you `xtset` your data, you need not do it again. The `xtset` information is stored with your data.

If you have previously `tsset` your data by using both a panel and a time variable, these settings will be recognized by `xtset`, and you need not `xtset` your data.

If your interest is in general time-series analysis, see [\[U\] 26.17 Models with time-series data](#) and the [Time-Series Reference Manual](#). If your interest is in multilevel mixed-effects models, see [\[U\] 26.19 Multilevel mixed-effects models](#) and the [Multilevel Mixed-Effects Reference Manual](#).

Setup

<code>xtset</code>	Declare data to be panel data
--------------------	-------------------------------

Data management and exploration tools

<code>xtdescribe</code>	Describe pattern of <code>xt</code> data
<code>xtsum</code>	Summarize <code>xt</code> data
<code>xttab</code>	Tabulate <code>xt</code> data
<code>xtdata</code>	Faster specification searches with <code>xt</code> data
<code>xtline</code>	Panel-data line plots

Linear regression estimators

<code>xtreg</code>	Fixed-, between-, and random-effects, and population-averaged linear models
<code>xtregar</code>	Fixed- and random-effects linear models with an AR(1) disturbance
<code>xtgls</code>	Panel-data models by using GLS
<code>xtpcse</code>	Linear regression with panel-corrected standard errors
<code>xthtaylor</code>	Hausman–Taylor estimator for error-components models
<code>xtfrontier</code>	Stochastic frontier models for panel data
<code>xtrc</code>	Random-coefficients regression
<code>xtivreg</code>	Instrumental variables and two-stage least squares for panel-data models

Unit-root tests

<code>xtunitroot</code>	Panel-data unit-root tests
-------------------------	----------------------------

Dynamic panel-data estimators

<code>xtabond</code>	Arellano–Bond linear dynamic panel-data estimation
<code>xtdpd</code>	Linear dynamic panel-data estimation
<code>xtdpdsys</code>	Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation

Censored-outcome estimators

<code>xttobit</code>	Random-effects tobit models
<code>xtintreg</code>	Random-effects interval-data regression models

Binary-outcome estimators

<code>xtlogit</code>	Fixed-effects, random-effects, and population-averaged logit models
<code>xtprobit</code>	Random-effects and population-averaged probit models
<code>xtcloglog</code>	Random-effects and population-averaged cloglog models

Ordinal-outcome estimators

<code>xtologit</code>	Random-effects ordered logistic models
<code>xtoprobit</code>	Random-effects ordered probit models

Count-data estimators

<code>xtpoisson</code>	Fixed-effects, random-effects, and population-averaged Poisson models
<code>xtnbreg</code>	Fixed-effects, random-effects, & population-averaged negative binomial models

Generalized estimating equations estimator

<code>xtgee</code>	Population-averaged panel-data models by using GEE
--------------------	--

Utility

<code>quadchk</code>	Check sensitivity of quadrature approximation
----------------------	---

Remarks and examples

Consider having data on n units—individuals, firms, countries, or whatever—over T periods. The data might be income and other characteristics of n persons surveyed each of T years, the output and costs of n firms collected over T months, or the health and behavioral characteristics of n patients collected over T years. In panel datasets, we write x_{it} for the value of x for unit i at time t . The xt commands assume that such datasets are stored as a sequence of observations on (i, t, x) .

For a discussion of panel-data models, see [Baltagi \(2013\)](#), [Greene \(2012, chap. 11\)](#), [Hsiao \(2003\)](#), and [Wooldridge \(2010\)](#). [Cameron and Trivedi \(2010\)](#) illustrate many of Stata's panel-data estimators.

➤ Example 1

If we had data on pulmonary function (measured by forced expiratory volume, or FEV) along with smoking behavior, age, sex, and height, a piece of the data might be

```
. list in 1/6, separator(0) divider
```

	pid	yr_visit	fev	age	sex	height	smokes
1.	1071	1991	1.21	25	1	69	0
2.	1071	1992	1.52	26	1	69	0
3.	1071	1993	1.32	28	1	68	0
4.	1072	1991	1.33	18	1	71	1
5.	1072	1992	1.18	20	1	71	1
6.	1072	1993	1.19	21	1	71	0

The xt commands need to know the identity of the variable identifying patient, and some of the xt commands also need to know the identity of the variable identifying time. With these data, we would type

```
. xtset pid yr_visit
```

If we resaved the data, we need not respecify xtset.



❑ Technical note

Panel data stored as shown above are said to be in the long form. Perhaps the data are in the wide form with 1 observation per unit and multiple variables for the value in each year. For instance, a piece of the pulmonary function data might be

pid	sex	fev91	fev92	fev93	age91	age92	age93
1071	1	1.21	1.52	1.32	25	26	28
1072	1	1.33	1.18	1.19	18	20	21

Data in this form can be converted to the long form by using `reshape`; see [\[D\] reshape](#).



➤ Example 2

Data for some of the periods might be missing. That is, we have panel data on $i = 1, \dots, n$ and $t = 1, \dots, T$, but only T_i of those observations are defined. With such missing periods—called unbalanced data—a piece of our pulmonary function data might be


```
. list in 1/6, separator(0) divider
```

	pid	yr_visit	fev	age	sex	height	smokes
1.	1071	1991	1.21	25	1	69	0
2.	1071	1992	1.52	26	1	69	0
3.	1071	1993	1.32	28	1	68	0
4.	1072	1991	1.33	18	1	71	1
5.	1072	1993	1.19	21	1	71	0
6.	1073	1991	1.47	24	0	64	0

Patient ID 1072 is not observed in 1992. The xt commands are robust to this problem.

◀

□ Technical note

In many of the entries in [XT], we will use data from a subsample of the NLSY data ([Center for Human Resource Research 1989](#)) on young women aged 14–26 years in 1968. Women were surveyed in each of the 21 years 1968–1988, except for the six years 1974, 1976, 1979, 1981, 1984, and 1986. We use two different subsets: `nlswork.dta` and `union.dta`.

For `nlswork.dta`, our subsample is of 4,711 women in years when employed, not enrolled in school and evidently having completed their education, and with wages in excess of \$1/hour but less than \$700/hour.


```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. describe

Contains data from http://www.stata-press.com/data/r13/nlswork.dta
   obs:                28,534              National Longitudinal Survey.
                                         Young Women 14-26 years of age
                                         in 1968
vars:                   21                27 Nov 2012 08:14
size:                  941,622
```

variable name	storage type	display format	value label	variable label
idcode	int	%8.0g		NLS ID
year	byte	%8.0g		interview year
birth_yr	byte	%8.0g		birth year
age	byte	%8.0g		age in current year
race	byte	%8.0g	racelbl	race
msp	byte	%8.0g		1 if married, spouse present
nev_mar	byte	%8.0g		1 if never married
grade	byte	%8.0g		current grade completed
collgrad	byte	%8.0g		1 if college graduate
not_smsa	byte	%8.0g		1 if not SMSA
c_city	byte	%8.0g		1 if central city
south	byte	%8.0g		1 if south
ind_code	byte	%8.0g		industry of employment
occ_code	byte	%8.0g		occupation
union	byte	%8.0g		1 if union
wks_ue	byte	%8.0g		weeks unemployed last year
ttl_exp	float	%9.0g		total work experience
tenure	float	%9.0g		job tenure, in years
hours	int	%8.0g		usual hours worked
wks_work	int	%8.0g		weeks worked last year
ln_wage	float	%9.0g		ln(wage/GNP deflator)

Sorted by: idcode year


```
. summarize
```

Variable	Obs	Mean	Std. Dev.	Min	Max
idcode	28534	2601.284	1487.359	1	5159
year	28534	77.95865	6.383879	68	88
birth_yr	28534	48.08509	3.012837	41	54
age	28510	29.04511	6.700584	14	46
race	28534	1.303392	.4822773	1	3
msp	28518	.6029175	.4893019	0	1
nev_mar	28518	.2296795	.4206341	0	1
grade	28532	12.53259	2.323905	0	18
collgrad	28534	.1680451	.3739129	0	1
not_smsa	28526	.2824441	.4501961	0	1
c_city	28526	.357218	.4791882	0	1
south	28526	.4095562	.4917605	0	1
ind_code	28193	7.692973	2.994025	1	12
occ_code	28413	4.777672	3.065435	1	13
union	19238	.2344319	.4236542	0	1
wks_ue	22830	2.548095	7.294463	0	76
ttl_exp	28534	6.215316	4.652117	0	28.88461
tenure	28101	3.123836	3.751409	0	25.91667
hours	28467	36.55956	9.869623	1	168
wks_work	27831	53.98933	29.03232	0	104
ln_wage	28534	1.674907	.4780935	0	5.263916

Many of the variables in the `nlswork` dataset are indicator variables, so we have used factor variables (see [U] 11.4.3 **Factor variables**) in many of the examples in this manual. You will see terms like `c.age#c.age` or `2.race` in estimation commands. `c.age#c.age` is just `age` interacted with `age`, or `age-squared`, and `2.race` is just an indicator variable for black (`race = 2`).

Instead of using factor variables, you could type

```
. generate age2 = age*age
. generate black = (race==2)
```

and substitute `age2` and `black` in your estimation command for `c.age#c.age` and `2.race`, respectively.

There are advantages, however, to using factor variables. First, you do not actually have to create new variables, so the number of variables in your dataset is less.

Second, by using factor variables, we are able to take better advantage of postestimation commands. For example, if we specify the simple model

```
. xtreg ln_wage age age2, fe
```

then `age` and `age2` are completely separate variables. Stata has no idea that they are related—that one is the square of the other. Consequently, if we compute the average marginal effect of `age` on the log of wages,

```
. margins, dydx(age)
```

then the reported marginal effect is with respect to the `age` variable alone and not with respect to the true effect of `age`, which involves the coefficients on both `age` and `age2`.

If instead we fit our model using an interaction of `age` with itself for the square of `age`,

```
. xtreg ln_wage age c.age#c.age, fe
```


then Stata has a deep understanding that the coefficients `age` and `c.age#c.age` are related. After fitting this model, the marginal effect reported by `margins` includes the full effect of `age` on the log of income, including the contribution of both coefficients.

```
. margins, dydx(age)
```

There are other reasons for preferring factor variables; see [\[R\] margins](#) for examples.

For `union.dta`, our subset was sampled only from those with union membership information from 1970 to 1988. Our subsample is of 4,434 women. The important variables are `age` (16–46), `grade` (years of schooling completed, ranging from 0 to 18), `not_smsa` (28% of the person-time was spent living outside a standard metropolitan statistical area (SMSA), and `south` (41% of the person-time was in the South). The dataset also has variable `union`. Overall, 22% of the person-time is marked as time under union membership, and 44% of these women have belonged to a union.

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. describe

Contains data from http://www.stata-press.com/data/r13/union.dta
  obs:      26,200      NLS Women 14-24 in 1968
  vars:       8          4 May 2013 13:54
  size:     235,800
```

variable name	storage type	display format	value label	variable label
idcode	int	%8.0g		NLS ID
year	byte	%8.0g		interview year
age	byte	%8.0g		age in current year
grade	byte	%8.0g		current grade completed
not_smsa	byte	%8.0g		1 if not SMSA
south	byte	%8.0g		1 if south
union	byte	%8.0g		1 if union
black	byte	%8.0g		race black

Sorted by: `idcode year`

```
. summarize
```

Variable	Obs	Mean	Std. Dev.	Min	Max
idcode	26200	2611.582	1484.994	1	5159
year	26200	79.47137	5.965499	70	88
age	26200	30.43221	6.489056	16	46
grade	26200	12.76145	2.411715	0	18
not_smsa	26200	.2837023	.4508027	0	1
south	26200	.4130153	.4923849	0	1
union	26200	.2217939	.4154611	0	1
black	26200	.274542	.4462917	0	1

In many of the examples where the `union` dataset is used, we also include an interaction between the `year` variable and the `south` variable—`south#c.year`. This interaction is created using factor-variables notation; see [\[U\] 11.4.3 Factor variables](#).

With both datasets, we have typed

```
. xtset idcode year
```



□ Technical note

The `xtset` command sets the t and i index for `xt` data by declaring them as characteristics of the data; see [P] [char](#). The panel variable is stored in `_dta[iis]` and the time variable is stored in `_dta[tis]`.



□ Technical note

Throughout the entries in [XT], when random-effects models are fit, a likelihood-ratio test that the variance of the random effects is zero is included. These tests occur on the boundary of the parameter space, invalidating the usual theory associated with such tests. However, these likelihood-ratio tests have been modified to be valid on the boundary. In particular, the null distribution of the likelihood-ratio test statistic is not the usual χ^2_1 but is rather a 50:50 mixture of a χ^2_0 (point mass at zero) and a χ^2_1 , denoted as $\bar{\chi}^2_{01}$. See [Gutierrez, Carter, and Drukker \(2001\)](#) for a full discussion.



References

- Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Cameron, A. C., and P. K. Trivedi. 2010. *Microeconometrics Using Stata*. Rev. ed. College Station, TX: Stata Press.
- Center for Human Resource Research. 1989. *National Longitudinal Survey of Labor Market Experience, Young Women 14–24 years of age in 1968*. Columbus, OH: Ohio State University Press.
- Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Gutierrez, R. G., S. L. Carter, and D. M. Drukker. 2001. [sg160: On boundary-value likelihood-ratio tests](#). *Stata Technical Bulletin* 60: 15–18. Reprinted in *Stata Technical Bulletin Reprints*, vol. 10, pp. 269–273. College Station, TX: Stata Press.
- Hsiao, C. 2003. *Analysis of Panel Data*. 2nd ed. New York: Cambridge University Press.
- Wooldridge, J. M. 2010. *Econometric Analysis of Cross Section and Panel Data*. 2nd ed. Cambridge, MA: MIT Press.

Also see

[XT] [xtset](#) — Declare data to be panel data

Title

quadchk — Check sensitivity of quadrature approximation

[Syntax](#)[Menu](#)[Description](#)[Options](#)[Remarks and examples](#)

Syntax

```
quadchk [ #1 #2 ] [ , nooutput nofrom ]
```

Menu

Statistics > Longitudinal/panel data > Setup and utilities > Check sensitivity of quadrature approximation

Description

quadchk checks the quadrature approximation used in the random-effects estimators of the following commands:

```
xtcloglog
xtintreg
xtlogit
xtologit
xtoprobit
xtpoisson, re with the normal option
xtprobit
xttobit
```

quadchk refits the model for different numbers of quadrature points and then compares the different solutions.

#1 and #2 specify the number of quadrature points to use in the comparison runs of the previous model. The default is to use (roughly) $2n_q/3$ and $4n_q/3$ points, where n_q is the number of quadrature points used in the original estimation.

Most options supplied to the original model are respected by quadchk, but some are not. These are `or`, `vce()`, and the *maximize_options*.

Options

`nooutput` suppresses the iteration log and output of the refitted models.

`nofrom` forces the refitted models to start from scratch rather than starting from the previous estimation results. Specifying the `nofrom` option can level the playing field in testing estimation results.

Remarks and examples

Remarks are presented under the following headings:

What makes a good random-effects model fit?

How do I know whether I have a good quadrature approximation?

What can I do to improve my results?

What makes a good random-effects model fit?

Some random-effects estimators in Stata use adaptive or nonadaptive Gauss–Hermite quadrature to compute the log likelihood and its derivatives. As a rule, adaptive quadrature, which is the default integration method, is much more accurate. The `quadchk` command provides a means to look at the numerical accuracy of either quadrature approximation. A good random-effects model fit depends on both the goodness of the quadrature approximation and the goodness of the data.

The accuracy of the quadrature approximation depends on three factors. The first and second are how many quadrature points are used and where the quadrature points fall. These two factors directly influence the accuracy of the quadrature approximation. The number of quadrature points may be specified with the `intpoints()` option. However, once the number of points is specified, their abscissas (locations) and corresponding weights are completely determined. Increasing the number of points expands the range of the abscissas and, to a lesser extent, increases the density of the abscissas. For this reason, a function that undulates between the abscissas can be difficult to approximate.

Third, the smoothness of the function being approximated influences the accuracy of the quadrature approximation. Gauss–Hermite quadrature estimates integrals of the type

$$\int_{-\infty}^{\infty} e^{-x^2} f(x) dx$$

and the approximation is exact if $f(x)$ is a polynomial of degree less than the number of integration points. Therefore, $f(x)$ that are well approximated by polynomials of a given degree have integrals that are well approximated by Gauss–Hermite quadrature with that given number of integration points. Both large panel sizes and high ρ can reduce the accuracy of the quadrature approximation.

A final factor affects the goodness of the random-effects model: the data themselves. For high ρ , for example, there is high intrapanel correlation, and panels look like observations. The model becomes unidentified. Here, even with exact quadrature, fitting the model would be difficult.

How do I know whether I have a good quadrature approximation?

`quadchk` is intended as a tool to help you know whether you have a good quadrature approximation. As a rule of thumb, if the coefficients do not change by more than a relative difference of 10^{-4} (0.01%), the choice of quadrature points does not significantly affect the outcome, and the results may be confidently interpreted. However, if the results do change appreciably—greater than a relative difference of 10^{-2} (1%)—then quadrature is not reliably approximating the likelihood.

What can I do to improve my results?

If the `quadchk` command indicates that the estimation results are sensitive to the number of quadrature points, there are several things you can do. First, if you are not using adaptive quadrature, switch to adaptive quadrature.

Adaptive quadrature can improve the approximation by transforming the integrand so that the abscissas and weights sample the function on a more suitable range. Details of this transformation are in *Methods and formulas* for the given commands; for example, see [\[XT\] xtprobit](#).

If the model still shows sensitivity to the number of quadrature points, increase the number of quadrature points with the `intpoints()` option. This option will increase the range and density of the sampling used for the quadrature approximation.

If neither of these works, you may then want to consider an alternative model, such as a fixed-effects, pooled, or population-averaged model. Alternatively, a different random-effects model whose likelihood is not approximated via quadrature (for example, `xtpoisson`, `re`) may be a better choice.

➤ Example 1

Here we synthesize data according to the model

$$E(y) = 0.05 x_1 + 0.08 x_2 + 0.08 x_3 + 0.1 x_4 + 0.1 x_5 + 0.1 x_6 + 0.1\epsilon$$
$$z = \begin{cases} 1 & \text{if } y \geq 0 \\ 0 & \text{if } y < 0 \end{cases}$$

where the intrapanel correlation is 0.5 and the x1 variable is constant within panels. We first fit a random-effects probit model, and then we check the stability of the quadrature calculation:

```
. use http://www.stata-press.com/data/r13/quad1
. xtset id
    panel variable:  id (balanced)
. xtprobit z x1-x6
    (output omitted)
Random-effects probit regression               Number of obs      =      6000
Group variable: id                           Number of groups   =      300
Random effects u_i ~ Gaussian                Obs per group: min =        20
                                              avg  =       20.0
                                              max  =        20
Integration method: mvaghermite              Integration points  =       12
Wald chi2(6)                                =       29.24
Prob > chi2                                  =       0.0001
Log likelihood = -3347.1097
```

z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
x1	.0043068	.0607058	0.07	0.943	-.1146743	.1232879
x2	.1000742	.066331	1.51	0.131	-.0299323	.2300806
x3	.1503539	.0662503	2.27	0.023	.0205057	.2802021
x4	.123015	.0377089	3.26	0.001	.0491069	.196923
x5	.1342988	.0657222	2.04	0.041	.0054856	.263112
x6	.0879933	.0455753	1.93	0.054	-.0013325	.1773192
_cons	.0757067	.060359	1.25	0.210	-.0425948	.1940083
/lnsig2u	-.0329916	.1026847			-.23425	.1682667
sigma_u	.9836395	.0505024			.889474	1.087774
rho	.4917528	.0256642			.4417038	.5419677

Likelihood-ratio test of rho=0: chibar2(01) = 1582.67 Prob >= chibar2 = 0.000


```
. quadchk
Refitting model intpoints() = 8
(output omitted)
Refitting model intpoints() = 16
(output omitted)
```

		Quadrature check			
		Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log		-3347.1097	-3347.1153	-3347.1099	
likelihood			-.00561484	-.00014288	Difference
			1.678e-06	4.269e-08	Relative difference
z:		.0043068	.0043068	.00430541	
	x1		8.983e-15	-1.388e-06	Difference
			2.086e-12	-.00032222	Relative difference
z:		.10007418	.10007418	.10007431	
	x2		2.540e-15	1.362e-07	Difference
			2.538e-14	1.361e-06	Relative difference
z:		.15035391	.15035391	.15035406	
	x3		6.356e-15	1.520e-07	Difference
			4.227e-14	1.011e-06	Relative difference
z:		.12301495	.12301495	.12301506	
	x4		4.149e-15	1.099e-07	Difference
			3.373e-14	8.931e-07	Relative difference
z:		.13429881	.13429881	.13429896	
	x5		4.913e-15	1.471e-07	Difference
			3.658e-14	1.096e-06	Relative difference
z:		.08799332	.08799332	.08799346	
	x6		3.358e-15	1.363e-07	Difference
			3.817e-14	1.549e-06	Relative difference
z:		.07570675	.07570675	.07570423	
	_cons		1.962e-14	-2.516e-06	Difference
			2.592e-13	-.00003323	Relative difference
lnsig2u:		-.03299164	-.03299164	-.03298184	
	_cons		7.268e-14	9.798e-06	Difference
			-2.203e-12	-.00029699	Relative difference

We see that the largest difference is in the x1 variable with a relative difference of 0.03% between the model with 12 integration points and 16. This example is somewhat rare in that the differences between eight quadrature points and 12 are smaller than those between 12 and 16. Usually the opposite occurs: the model results converge as you add quadrature points. Here we have an indication that perhaps some minor feature of the model was missed with eight points and 12 but seen with 16. Because all differences are very small, we could accept this model as is. We would like to have a largest relative difference of about 0.01%, and this is close. The differences and relative differences are small, indicating that refitting the random-effects probit model with a few more integration points will yield a satisfactory result. Indeed, refitting the model with the `intpoints(20)` option yields completely satisfactory results when checked with `quadchk`.

Nonadaptive Gauss–Hermite quadrature does not yield such robust results.

. xtprobit z x1-x6, intmethod(ghermite) nolog

Random-effects probit regression

Group variable: id

Random effects u_i ~ Gaussian

Integration method: ghermite

Log likelihood = -3349.6926

Number of obs = 6000

Number of groups = 300

Obs per group: min = 20

avg = 20.0

max = 20

Integration points = 12

Wald chi2(6) = 36.15

Prob > chi2 = 0.0000

z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
x1	.1156763	.0554925	2.08	0.037	.0069131	.2244396
x2	.1005555	.066227	1.52	0.129	-.0292469	.230358
x3	.1542187	.0660852	2.33	0.020	.0246941	.2837433
x4	.1257616	.0375776	3.35	0.001	.0521108	.1994123
x5	.1366003	.0654696	2.09	0.037	.0082823	.2649182
x6	.0870325	.0453489	1.92	0.055	-.0018497	.1759147
_cons	.1098393	.0500514	2.19	0.028	.0117404	.2079382
/lnsig2u	-.0791821	.0971063			-.2695071	.1111428
sigma_u	.9611824	.0466685			.8739313	1.057145
rho	.4802148	.0242386			.4330281	.5277571

Likelihood-ratio test of rho=0: chibar2(01) = 1577.50 Prob >= chibar2 = 0.000


```
. quadchk, nooutput
Refitting model intpoints() = 8
Refitting model intpoints() = 16
```

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-3349.6926	-3354.6372 -4.9446636 .00147615	-3348.3881 1.3045063 -.00038944	Difference Relative difference
z: x1	.11567633	.16153998 .04586365 .39648262	.07007833 -.045598 -.39418608	Difference Relative difference
z: x2	.10055552	.10317831 .00262279 .02608297	.09937417 -.00118135 -.01174825	Difference Relative difference
z: x3	.1542187	.15465369 .00043499 .00282062	.15150516 -.00271354 -.0175954	Difference Relative difference
z: x4	.12576159	.12880254 .00304096 .02418032	.1243974 -.00136418 -.01084739	Difference Relative difference
z: x5	.13660028	.13475211 -.00184817 -.01352978	.13707075 .00047047 .00344411	Difference Relative difference
z: x6	.08703252	.08568342 -.0013491 -.0155011	.08738135 .00034883 .00400809	Difference Relative difference
z: _cons	.10983928	.11031299 .00047371 .00431274	.09654975 -.01328953 -.12099067	Difference Relative difference
lnsig2u: _cons	-.07918212	-.18133821 -.10215609 1.2901408	-.05815644 .02102568 -.26553572	Difference Relative difference

Here we see that the x1 variable (the one that was constant within panel) changed with a relative difference of nearly 40%! This example clearly demonstrates the benefit of adaptive quadrature methods.

➤ Example 2

Here we rerun the [previous](#) nonadaptive quadrature model, but using the `intpoints(120)` option to increase the number of integration points to 120. We get results close to those from adaptive quadrature and an acceptable `quadchk`. This example demonstrates the efficacy of increasing the number of integration points to improve the quadrature approximation.

```
. xtprobit z x1-x6, intmethod(ghermite) intpoints(120) nolog
Random-effects probit regression          Number of obs      =      6000
Group variable: id                      Number of groups   =       300
Random effects u_i ~ Gaussian           Obs per group: min =        20
                                         avg =       20.0
                                         max =        20

Integration method: ghermite             Integration points =       120
                                         Wald chi2(6)      =       29.24
Log likelihood = -3347.1099              Prob > chi2       =      0.0001
```

	z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
	x1	.0043059	.0607087	0.07	0.943	-.114681	.1232929
	x2	.1000743	.0663311	1.51	0.131	-.0299322	.2300808
	x3	.1503541	.0662503	2.27	0.023	.0205058	.2802023
	x4	.1230151	.0377089	3.26	0.001	.049107	.1969232
	x5	.134299	.0657223	2.04	0.041	.0054856	.2631123
	x6	.0879935	.0455753	1.93	0.054	-.0013325	.1773194
	_cons	.0757054	.0603621	1.25	0.210	-.0426021	.1940128
/lnsig2u		-.0329832	.1026863			-.2342446	.1682783
sigma_u		.9836437	.0505034			.8894764	1.08778
rho		.491755	.0256646			.4417052	.5419706

Likelihood-ratio test of rho=0: chibar2(01) = 1582.67 Prob >= chibar2 = 0.000


```
. quadchk, nooutput
Refitting model intpoints() = 80
Refitting model intpoints() = 160
```

Quadrature check				
	Fitted quadrature 120 points	Comparison quadrature 80 points	Comparison quadrature 160 points	
Log likelihood	-3347.1099	-3347.1099 -.00007138 2.133e-08	-3347.1099 2.440e-07 -7.289e-11	Difference Relative difference
z: x1	.00430592	.00431318 7.259e-06 .00168592	.00430553 -3.871e-07 -.00008991	Difference Relative difference
z: x2	.10007431	.10007415 -1.519e-07 -1.517e-06	.10007431 5.585e-09 5.580e-08	Difference Relative difference
z: x3	.15035406	.15035407 1.699e-08 1.130e-07	.15035406 7.636e-09 5.078e-08	Difference Relative difference
z: x4	.12301506	.12301512 6.036e-08 4.907e-07	.12301506 5.353e-09 4.352e-08	Difference Relative difference
z: x5	.13429895	.13429962 6.646e-07 4.949e-06	.13429896 4.785e-09 3.563e-08	Difference Relative difference
z: x6	.08799345	.08799334 -1.123e-07 -1.276e-06	.08799346 3.049e-09 3.465e-08	Difference Relative difference
z: _cons	.07570536	.07570205 -3.305e-06 -.00004365	.07570442 -9.405e-07 -.00001242	Difference Relative difference
lnsig2u: _cons	-.03298317	-.03298909 -5.919e-06 .00017945	-.03298186 1.304e-06 -.00003952	Difference Relative difference

◀

► Example 3

Here we synthesize data the same way as in the [previous example](#), but we make the intrapanel correlation equal to 0.1 instead of 0.5. We again fit a random-effects probit model and check the quadrature:


```
. use http://www.stata-press.com/data/r13/quad2
. xtset id
    panel variable:  id (balanced)
. xtprobit z x1-x6
Fitting comparison model:
Iteration 0:  log likelihood = -4142.2915
Iteration 1:  log likelihood = -4120.4109
Iteration 2:  log likelihood = -4120.4099
Iteration 3:  log likelihood = -4120.4099
Fitting full model:
rho = 0.0      log likelihood = -4120.4099
rho = 0.1      log likelihood = -4065.7986
rho = 0.2      log likelihood = -4087.7703
Iteration 0:  log likelihood = -4065.7986
Iteration 1:  log likelihood = -4065.3157
Iteration 2:  log likelihood = -4065.3144
Iteration 3:  log likelihood = -4065.3144
Random-effects probit regression
Group variable: id
Random effects u_i ~ Gaussian
Number of obs      =      6000
Number of groups   =       300
Obs per group: min =        20
                  avg =       20.0
                  max =        20
Integration method: mvaghermite
Integration points =        12
Wald chi2(6)       =       39.43
Prob > chi2        =       0.0000
Log likelihood     = -4065.3144
```

z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
x1	.0246943	.025112	0.98	0.325	-.0245243	.0739129
x2	.1300123	.0587906	2.21	0.027	.0147847	.2452398
x3	.1190409	.0579539	2.05	0.040	.0054533	.2326284
x4	.139197	.0331817	4.19	0.000	.0741621	.2042319
x5	.077364	.0578454	1.34	0.181	-.036011	.1907389
x6	.0862028	.0401185	2.15	0.032	.007572	.1648336
_cons	.0922653	.0244392	3.78	0.000	.0443653	.1401652
/lnsig2u	-2.343939	.1575275			-2.652687	-2.035191
sigma_u	.3097563	.0243976			.2654461	.3614631
rho	.0875487	.0125839			.0658236	.1155574

Likelihood-ratio test of rho=0: chibar2(01) = 110.19 Prob >= chibar2 = 0.000

. quadchk, nooutput				
Refitting model intpoints() = 8				
Refitting model intpoints() = 16				
Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-4065.3144	-4065.3144 -2.268e-08 5.578e-12	-4065.3144 5.457e-12 -1.342e-15	Difference Relative difference
z: x1	.02469427	.02469427 -3.645e-12 -1.476e-10	.02469427 -8.007e-12 -3.242e-10	Difference Relative difference
z: x2	.13001229	.13001229 -1.566e-11 -1.204e-10	.13001229 -6.880e-13 -5.292e-12	Difference Relative difference
z: x3	.11904089	.11904089 -6.457e-12 -5.425e-11	.11904089 -3.030e-13 -2.545e-12	Difference Relative difference
z: x4	.13919697	.13919697 1.442e-12 1.036e-11	.13919697 1.693e-13 1.216e-12	Difference Relative difference
z: x5	.07736398	.07736398 -5.801e-12 -7.499e-11	.07736398 -4.557e-13 -5.890e-12	Difference Relative difference
z: x6	.08620282	.08620282 5.903e-12 6.848e-11	.08620282 3.191e-13 3.701e-12	Difference Relative difference
z: _cons	.09226527	.09226527 -2.850e-12 -3.089e-11	.09226527 -1.837e-11 -1.991e-10	Difference Relative difference
lnsig2u: _cons	-2.3439389	-2.3439389 -2.946e-09 1.257e-09	-2.3439389 -2.172e-10 9.267e-11	Difference Relative difference

Here we see that the quadrature approximation is stable. With this result, we can confidently interpret the results. Satisfactory results are also obtained in this case with nonadaptive quadrature.

Syntax
Methods and formulas

Description
Reference

Options
Also see

Remarks and examples

Syntax

estimation_cmd ... [, *vce_options* ...]

<i>vce_options</i>	Description
<code>vce(oim)</code>	observed information matrix (OIM)
<code>vce(opg)</code>	outer product of the gradient (OPG) vectors
<code>vce(robust)</code>	Huber/White/sandwich estimator
<code>vce(cluster <i>clustvar</i>)</code>	clustered sandwich estimator
<code>vce(bootstrap [, <i>bootstrap_options</i>])</code>	bootstrap estimation
<code>vce(jackknife [, <i>jackknife_options</i>])</code>	jackknife estimation
<code>nmp</code>	use divisor $N - P$ instead of the default N
<code>scale(x2 dev phi #)</code>	override the default scale parameter; available only with population-averaged models

Description

This entry describes the *vce_options*, which are common to most xt estimation commands. Not all the options documented below work with all xt estimation commands; see the documentation for the particular estimation command. If an option is listed there, it is applicable.

The `vce()` option specifies how to estimate the variance–covariance matrix (VCE) corresponding to the parameter estimates. The standard errors reported in the table of parameter estimates are the square root of the variances (diagonal elements) of the VCE.

Options

SE/Robust

`vce(oim)` is usually the default for models fit using maximum likelihood. `vce(oim)` uses the observed information matrix (OIM); see [\[R\] ml](#).

`vce(opg)` uses the sum of the outer product of the gradient (OPG) vectors; see [\[R\] ml](#). This is the default VCE when the `technique(bhhh)` option is specified; see [\[R\] maximize](#).

`vce(robust)` uses the robust or sandwich estimator of variance. This estimator is robust to some types of misspecification so long as the observations are independent; see [\[U\] 20.21 Obtaining robust variance estimates](#).

If the command allows `pweights` and you specify them, `vce(robust)` is implied; see [\[U\] 20.23.3 Sampling weights](#).

`vce(cluster clustvar)` specifies that the standard errors allow for intragroup correlation, relaxing the usual requirement that the observations be independent. That is to say, the observations are independent across groups (clusters) but not necessarily within groups. *clustvar* specifies to which group each observation belongs, for example, `vce(cluster personid)` in data with repeated observations on individuals. `vce(cluster clustvar)` affects the standard errors and variance-covariance matrix of the estimators but not the estimated coefficients; see [U] 20.21 [Obtaining robust variance estimates](#).

`vce(bootstrap [, bootstrap_options])` uses a nonparametric bootstrap; see [R] [bootstrap](#). After estimation with `vce(bootstrap)`, see [R] [bootstrap postestimation](#) to obtain percentile-based or bias-corrected confidence intervals.

`vce(jackknife [, jackknife_options])` uses the delete-one jackknife; see [R] [jackknife](#).

`nmp` specifies that the divisor $N - P$ be used instead of the default N , where N is the total number of observations and P is the number of coefficients estimated.

`scale(x2|dev|phi|#)` overrides the default scale parameter. By default, `scale(1)` is assumed for the discrete distributions (binomial, negative binomial, and Poisson), and `scale(x2)` is assumed for the continuous distributions (gamma, Gaussian, and inverse Gaussian).

`scale(x2)` specifies that the scale parameter be set to the Pearson chi-squared (or generalized chi-squared) statistic divided by the residual degrees of freedom, which is recommended by [McCullagh and Nelder \(1989\)](#) as a good general choice for continuous distributions.

`scale(dev)` sets the scale parameter to the deviance divided by the residual degrees of freedom. This option provides an alternative to `scale(x2)` for continuous distributions and for over- or underdispersed discrete distributions.

`scale(phi)` specifies that the scale parameter be estimated from the data. `xtgee`'s default scaling makes results agree with other estimators and has been recommended by [McCullagh and Nelder \(1989\)](#) in the context of GLM. When comparing results with calculations made by other software, you may find that the other packages do not offer this feature. In such cases, specifying `scale(phi)` should match their results.

`scale(#)` sets the scale parameter to `#`. For example, using `scale(1)` in `family(gamma)` models results in exponential-errors regression (if you assume independent correlation structure).

Remarks and examples

When you are working with panel-data models, we strongly encourage you to use the `vce(bootstrap)` or `vce(jackknife)` option instead of the corresponding prefix command. For example, to obtain jackknife standard errors with `xtlogit`, type


```
. use http://www.stata-press.com/data/r13/clogitid
```

```
. xtlogit y x1 x2, fe vce(jackknife)
```

```
(running xtlogit on estimation sample)
```

```
Jackknife replications (66)
```

```
|-----| 1 |-----| 2 |-----| 3 |-----| 4 |-----| 5  
..... 50  
.....
```

```
Conditional fixed-effects logistic regression      Number of obs       =        369  
Group variable: id                               Number of groups     =         66  
  
Obs per group: min =          2  
                  avg   =        5.6  
                  max   =        10  
  
F(           2,            65) =         4.58  
Prob > F                =        0.0137
```

```
Log likelihood    = -123.41386
```

```
(Replications based on 66 clusters in id)
```

y	Coef.	Jackknife Std. Err.	t	P> t	[95% Conf. Interval]	
x1	.653363	.3010608	2.17	0.034	.052103	1.254623
x2	.0659169	.0487858	1.35	0.181	-.0315151	.1633489

If you wish to specify more options to the bootstrap or jackknife estimation, you can include them within the `vce()` option. Below we refit our model requesting bootstrap standard errors based on 300 replications, we set the random-number seed so that our results can be reproduced, and we suppress the display of the replication dots.

```
. xtlogit y x1 x2, fe vce(bootstrap, reps(300) seed(123) nodots)
```

Conditional fixed-effects logistic regression	Number of obs	=	369
Group variable: id	Number of groups	=	66
	Obs per group:	min =	2
		avg =	5.6
		max =	10
	Wald chi2(2)	=	8.52
Log likelihood = -123.41386	Prob > chi2	=	0.0141

(Replications based on 66 clusters in id)

y	Observed Coef.	Bootstrap Std. Err.	z	P> z	Normal-based [95% Conf. Interval]	
x1	.653363	.3015317	2.17	0.030	.0623717	1.244354
x2	.0659169	.0512331	1.29	0.198	-.0344981	.1663319

❏ Technical note

To perform jackknife estimation on panel data, you must omit entire panels rather than individual observations. To replicate the output above using the `jackknife` prefix command, you would have to type

```
. jackknife, cluster(id): xtlogit y x1 x2, fe
(output omitted)
```

Similarly, bootstrap estimation on panel data requires you to resample entire panels rather than individual observations. The `vce(bootstrap)` and `vce(jackknife)` options handle this for you automatically.



Methods and formulas

By default, Stata's maximum likelihood estimators display standard errors based on variance estimates given by the inverse of the negative Hessian (second derivative) matrix. If `vce(robust)`, `vce(cluster clustvar)`, or `pweights` are specified, standard errors are based on the robust variance estimator (see [U] 20.21 **Obtaining robust variance estimates**); likelihood-ratio tests are not appropriate here (see [SVY] **survey**), and the model χ^2 is from a Wald test. If `vce(opg)` is specified, the standard errors are based on the outer product of the gradients; this option has no effect on likelihood-ratio tests, though it does affect Wald tests.

If `vce(bootstrap)` or `vce(jackknife)` is specified, the standard errors are based on the chosen replication method; here the model χ^2 or F statistic is from a Wald test using the respective replication-based covariance matrix. The t distribution is used in the coefficient table when the `vce(jackknife)` option is specified. `vce(bootstrap)` and `vce(jackknife)` are also available with some commands that are not maximum likelihood estimators.

Reference

McCullagh, P., and J. A. Nelder. 1989. *Generalized Linear Models*. 2nd ed. London: Chapman & Hall/CRC.

Also see

[R] **bootstrap** — Bootstrap sampling and estimation

[R] **jackknife** — Jackknife estimation

[R] **ml** — Maximum likelihood estimation

[U] 20 **Estimation and postestimation commands**

Syntax
Remarks and examples
Also see

Menu
Stored results

Description
Methods and formulas

Options
References

Syntax

xtabond *depvar* [*indepvars*] [*if*] [*in*] [, *options*]

<i>options</i>	Description
Model	
<u>no</u> constant	suppress constant term
<u>diff</u> vars(<i>varlist</i>)	already-differenced exogenous variables
<u>inst</u> (<i>varlist</i>)	additional instrument variables
<u>lags</u> (#)	use # lags of dependent variable as covariates; default is <code>lags(1)</code>
<u>maxl</u> dep(#)	maximum lags of dependent variable for use as instruments
<u>maxl</u> ags(#)	maximum lags of predetermined and endogenous variables for use as instruments
<u>two</u> step	compute the two-step estimator instead of the one-step estimator
Predetermined	
<u>pre</u> (<i>varlist</i> [...])	predetermined variables; can be specified more than once
Endogenous	
<u>endo</u> genous(<i>varlist</i> [...])	endogenous variables; can be specified more than once
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <code>gmm</code> or <u>r</u> obust
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>art</u> ests(#)	use # as maximum order for AR tests; default is <code>artests(2)</code>
<i>display_options</i>	control spacing and line width
<u>coef</u> legend	display legend instead of statistics

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.

indepvars and all *varlists*, except `pre(varlist[...])` and `endogenous(varlist[...])`, may contain time-series operators; see [U] 11.4.4 Time-series varlists. The specification of *depvar*, however, may not contain time-series operators.

`by`, `statsby`, and `xi` are allowed; see [U] 11.1.10 Prefix commands.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Arellano-Bond estimation

Description

Linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. Arellano and Bond (1991) derived a consistent generalized method of moments (GMM) estimator for the parameters of this model; `xtabond` implements this estimator.

This estimator is designed for datasets with many panels and few periods, and it requires that there be no autocorrelation in the idiosyncratic errors. For a related estimator that uses additional moment conditions, but still requires no autocorrelation in the idiosyncratic errors, see [XT] `xtdpdsys`. For estimators that allow for some autocorrelation in the idiosyncratic errors, at the cost of a more complicated syntax, see [XT] `xtddpd`.

Options

Model

`noconstant`; see [R] [estimation options](#).

`diffvars(varlist)` specifies a set of variables that already have been differenced to be included as strictly exogenous covariates.

`inst(varlist)` specifies a set of variables to be used as additional instruments. These instruments are not differenced by `xtabond` before including them in the instrument matrix.

`lags(#)` sets p , the number of lags of the dependent variable to be included in the model. The default is $p = 1$.

`maxldp(#)` sets the maximum number of lags of the dependent variable that can be used as instruments. The default is to use all $T_i - p - 2$ lags.

`maxlags(#)` sets the maximum number of lags of the predetermined and endogenous variables that can be used as instruments. For predetermined variables, the default is to use all $T_i - p - 1$ lags. For endogenous variables, the default is to use all $T_i - p - 2$ lags.

`twostep` specifies that the two-step estimator be calculated.

Predetermined

`pre(varlist[, lagstruct(prelags, premaxlags)])` specifies that a set of predetermined variables be included in the model. Optionally, you may specify that *prelags* lags of the specified variables also be included. The default for *prelags* is 0. Specifying *premaxlags* sets the maximum number of further lags of the predetermined variables that can be used as instruments. The default is to include $T_i - p - 1$ lagged levels as instruments for predetermined variables. You may specify as many sets of predetermined variables as you need within the standard Stata limits on matrix size. Each set of predetermined variables may have its own number of *prelags* and *premaxlags*.

Endogenous

`endogenous(varlist[, lagstruct(endlags, endmaxlags)])` specifies that a set of endogenous variables be included in the model. Optionally, you may specify that *endlags* lags of the specified variables also be included. The default for *endlags* is 0. Specifying *endmaxlags* sets the maximum number of further lags of the endogenous variables that can be used as instruments. The default is to include $T_i - p - 2$ lagged levels as instruments for endogenous variables. You may specify as many sets of endogenous variables as you need within the standard Stata limits on matrix size. Each set of endogenous variables may have its own number of *endlags* and *endmaxlags*.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see *Remarks and examples* below.

`vce(gmm)`, the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

`vce(robust)` uses the robust estimator. After one-step estimation, this is the Arellano–Bond robust VCE estimator. After two-step estimation, this is the [Windmeijer \(2005\)](#) WC-robust estimator.

Reporting

`level(#)`; see [\[R\] estimation options](#).

`artests(#)` specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by `estat abond`; see [\[XT\] xtabond postestimation](#). Specifying the order of the highest test at estimation time is more efficient than specifying it to `estat abond`, because `estat abond` must refit the model to obtain the test statistics. The maximum order must be less than or equal to the number of periods in the longest panel. The default is `artests(2)`.

display_options: `vsquish` and `nolstretch`; see [\[R\] estimation options](#).

The following option is available with `xtabond` but is not shown in the dialog box:

`coeflegend`; see [\[R\] estimation options](#).

Remarks and examples

[Anderson and Hsiao \(1981, 1982\)](#) propose using further lags of the level or the difference of the dependent variable to instrument the lagged dependent variables that are included in a dynamic panel-data model after the panel-level effects have been removed by first-differencing. A version of this estimator can be obtained from `xtivreg` (see [\[XT\] xtivreg](#)). [Arellano and Bond \(1991\)](#) build upon this idea by noting that, in general, there are many more instruments available. Building on [Holtz-Eakin, Newey, and Rosen \(1988\)](#) and using the GMM framework developed by [Hansen \(1982\)](#), they identify how many lags of the dependent variable, the predetermined variables, and the endogenous variables are valid instruments and how to combine these lagged levels with first differences of the strictly exogenous variables into a potentially large instrument matrix. Using this instrument matrix, [Arellano and Bond \(1991\)](#) derive the corresponding one-step and two-step GMM estimators, as well as the robust VCE estimator for the one-step model. They also found that the robust two-step VCE was seriously biased. [Windmeijer \(2005\)](#) worked out a bias-corrected (WC) robust estimator for VCEs of two-step GMM estimators, which is implemented in `xtabond`. The test of autocorrelation of order m and the Sargan test of overidentifying restrictions derived by [Arellano and Bond \(1991\)](#) can be obtained with `estat abond` and `estat sargan`, respectively; see [\[XT\] xtabond postestimation](#).

► Example 1: One-step estimator

[Arellano and Bond \(1991\)](#) apply their new estimators and test statistics to a model of dynamic labor demand that had previously been considered by [Layard and Nickell \(1986\)](#) using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm i and time t . In this dataset, n_{it} is the log of employment in firm i at time t , w_{it} is the natural log of the real product wage, k_{it} is the natural log of the gross capital stock, and ys_{it} is the natural log of industry output. The model also includes time dummies `yr1980`, `yr1981`, `yr1982`, `yr1983`, and `yr1984`. In table 4 of [Arellano and Bond \(1991\)](#), the authors present the results they obtained from several specifications.

In column a1 of table 4, Arellano and Bond report the coefficients and their standard errors from the robust one-step estimators of a dynamic model of labor demand in which n_{it} is the dependent variable and its first two lags are included as regressors. To clarify some important issues, we will begin with the homoskedastic one-step version of this model and then consider the robust case. Here is the command using `xtabond` and the subsequent output for the homoskedastic case:

```
. use http://www.stata-press.com/data/r13/abdata
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) noconstant
Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                               Number of groups     =      140
Time variable: year
Obs per group:      min =      4
                   avg =  4.364286
                   max =      6
Number of instruments =      41                  Wald chi2(16)        =    1757.07
                                                Prob > chi2          =     0.0000

One-step results
```

n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6862261	.1486163	4.62	0.000	.3949435	.9775088
L2.	-.0853582	.0444365	-1.92	0.055	-.1724523	.0017358
w						
--.	-.6078208	.0657694	-9.24	0.000	-.7367265	-.4789151
L1.	.3926237	.1092374	3.59	0.000	.1785222	.6067251
k						
--.	.3568456	.0370314	9.64	0.000	.2842653	.4294259
L1.	-.0580012	.0583051	-0.99	0.320	-.172277	.0562747
L2.	-.0199475	.0416274	-0.48	0.632	-.1015357	.0616408
ys						
--.	.6085073	.1345412	4.52	0.000	.3448115	.8722031
L1.	-.7111651	.1844599	-3.86	0.000	-1.0727	-.3496304
L2.	.1057969	.1428568	0.74	0.459	-.1741974	.3857912
yr1980	.0029062	.0212705	0.14	0.891	-.0387832	.0445957
yr1981	-.0404378	.0354707	-1.14	0.254	-.1099591	.0290836
yr1982	-.0652767	.048209	-1.35	0.176	-.1597646	.0292111
yr1983	-.0690928	.0627354	-1.10	0.271	-.1920521	.0538664
yr1984	-.0650302	.0781322	-0.83	0.405	-.2181665	.0881061
year	.0095545	.0142073	0.67	0.501	-.0182912	.0374002

```
Instruments for differenced equation
GMM-type: L(2/.)n
Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980
          D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year
```

The coefficients are identical to those reported in column a1 of table 4, as they should be. Of course, the standard errors are different because we are considering the homoskedastic case. Although the moment conditions use first-differenced errors, `xtabond` estimates the coefficients of the level model and reports them accordingly.

The footer in the output reports the instruments used. The first line indicates that `xtabond` used lags from 2 on back to create the GMM-type instruments described in [Arellano and Bond \(1991\)](#) and [Holtz-Eakin, Newey, and Rosen \(1988\)](#); also see [Methods and formulas](#) in [XT] `xtdpd`. The second and third lines indicate that the first difference of all the exogenous variables were used as standard instruments. GMM-type instruments use the lags of a variable to contribute multiple columns to the

instrument matrix, whereas each standard instrument contributes one column to the instrument matrix. The notation `L(2/.) .n` indicates that GMM-type instruments were created using lag 2 of `n` from on back. `(L(2/4) .n` would indicate that GMM-type instruments were created using only lags 2, 3, and 4 of `n`.)

After `xtabond`, `estat sargan` reports the Sargan test of overidentifying restrictions.

```
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(25)      = 65.81806
Prob > chi2    = 0.0000
```

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, `xtabond` does not compute it when `vce(robust)` is specified. The Sargan test, reported by [Arellano and Bond \(1991, table 4, column a1\)](#), comes from the one-step homoskedastic estimator and is the same as the one reported here. The output above presents strong evidence against the null hypothesis that the overidentifying restrictions are valid. Rejecting this null hypothesis implies that we need to reconsider our model or our instruments, unless we attribute the rejection to heteroskedasticity in the data-generating process. Although performing the Sargan test after the two-step estimator is an alternative, [Arellano and Bond \(1991\)](#) found a tendency for this test to underreject in the presence of heteroskedasticity. (See [\[XT\] xtdpd](#) for an [example](#) indicating that this rejection may be due to misspecification.)

By default, `xtabond` calculates the Arellano–Bond test for first- and second-order autocorrelation in the first-differenced errors. (Use `artests()` to compute tests for higher orders.) There are versions of this test for both the homoskedastic and the robust cases, although their values are different. Use `estat abond` to report the test results.

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-3.9394	0.0001
2	-.54239	0.5876

H0: no autocorrelation

When the idiosyncratic errors are independently and identically distributed (i.i.d.), the first-differenced errors are first-order serially correlated. So, as expected, the output above presents strong evidence against the null hypothesis of zero autocorrelation in the first-differenced errors at order 1. Serial correlation in the first-differenced errors at an order higher than 1 implies that the moment conditions used by `xtabond` are not valid; see [\[XT\] xtdpd](#) for an [example](#) of an alternative estimation method. The output above presents no significant evidence of serial correlation in the first-differenced errors at order 2.



► Example 2: A one-step estimator with robust VCE

Consider the output from the one-step robust estimator of the same model:

```
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) vce(robust)
> noconstant

Arellano-Bond dynamic panel-data estimation   Number of obs       =       611
Group variable: id                           Number of groups      =       140
Time variable: year

Obs per group:   min =         4
                  avg =    4.364286
                  max =         6

Number of instruments =       41                Wald chi2(16)         =    1727.45
                                                Prob > chi2          =     0.0000

One-step results
                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6862261	.1445943	4.75	0.000	.4028266	.9696257
L2.	-.0853582	.0560155	-1.52	0.128	-.1951467	.0244302
w						
--.	-.6078208	.1782055	-3.41	0.001	-.9570972	-.2585445
L1.	.3926237	.1679931	2.34	0.019	.0633632	.7218842
k						
--.	.3568456	.0590203	6.05	0.000	.241168	.4725233
L1.	-.0580012	.0731797	-0.79	0.428	-.2014308	.0854284
L2.	-.0199475	.0327126	-0.61	0.542	-.0840631	.0441681
ys						
--.	.6085073	.1725313	3.53	0.000	.2703522	.9466624
L1.	-.7111651	.2317163	-3.07	0.002	-1.165321	-.2570095
L2.	.1057969	.1412021	0.75	0.454	-.1709542	.382548
yr1980	.0029062	.0158028	0.18	0.854	-.0280667	.0338791
yr1981	-.0404378	.0280582	-1.44	0.150	-.0954307	.0145552
yr1982	-.0652767	.0365451	-1.79	0.074	-.1369038	.0063503
yr1983	-.0690928	.047413	-1.46	0.145	-.1620205	.0238348
yr1984	-.0650302	.0576305	-1.13	0.259	-.1779839	.0479235
year	.0095545	.0102896	0.93	0.353	-.0106127	.0297217

Instruments for differenced equation

GMM-type: L(2/.)n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980
D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

The coefficients are the same, but now the standard errors match that reported in [Arellano and Bond \(1991, table 4, column a1\)](#). Most of the robust standard errors are higher than those that assume a homoskedastic error term.

The Sargan statistic cannot be calculated after requesting a robust VCE, but robust tests for serial correlation are available.

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-3.5996	0.0003
2	-.51603	0.6058

```
HO: no autocorrelation
```

The value of the test for second-order autocorrelation matches those reported in [Arellano and Bond \(1991, table 4, column a1\)](#) and presents no evidence of model misspecification.



➤ Example 3: The Wald model test

xtabond reports the Wald statistic of the null hypothesis that all the coefficients except the constant are zero. Here the null hypothesis is that all the coefficients are zero, because there is no constant in the model. In our [previous example](#), the null hypothesis is soundly rejected. In column a1 of table 4, Arellano and Bond report a chi-squared test of the null hypothesis that all the coefficients are zero, except the time trend and the time dummies. Here is this test in Stata:

```
. test l.n l2.n w l.w k l.k l2.k ys l.ys l2.ys
( 1)  L.n = 0
( 2)  L2.n = 0
( 3)  w = 0
( 4)  L.w = 0
( 5)  k = 0
( 6)  L.k = 0
( 7)  L2.k = 0
( 8)  ys = 0
( 9)  L.ys = 0
(10)  L2.ys = 0
      chi2( 10) =   408.29
      Prob > chi2 =    0.0000
```



➤ Example 4: A two-step estimator with Windmeijer bias-corrected robust VCE

The two-step estimator with the Windmeijer bias-corrected robust VCE of the same model produces the following output:

The test for autocorrelation presents no evidence of model misspecification:

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-2.1255	0.0335
2	-.35166	0.7251

H0: no autocorrelation



Manuel Arellano (1957–) was born in Elda in Alicante, Spain. He earned degrees in economics from the University of Barcelona and the London School of Economics. After various posts in Oxford and London, he returned to Spain as professor of econometrics at Madrid in 1991. He is a leading expert on panel-data econometrics.

Stephen Roy Bond (1963–) earned degrees in economics from Cambridge and Oxford. Following various posts at Oxford, he now works mainly at the Institute for Fiscal Studies in London. His research interests include company taxation, dividends, and the links between financial markets, corporate control, and investment.

➤ Example 5: Including an estimator for the constant

Thus far we have been specifying the `noconstant` option to keep to the standard Arellano–Bond estimator, which uses instruments only for the differenced equation. The constant estimated by `xtabond` is a constant in the level equation, and it is estimated from the level errors. The output below illustrates that including a constant in the model does not affect the other parameter estimates.


```
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) twostep vce(robust)
Arellano-Bond dynamic panel-data estimation   Number of obs       =       611
Group variable: id                           Number of groups      =       140
Time variable: year

Obs per group:   min =         4
                  avg =    4.364286
                  max =         6

Number of instruments =       42                Wald chi2(16)         =    1104.72
                                                Prob > chi2           =     0.0000

Two-step results
                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6287089	.1934138	3.25	0.001	.2496248	1.007793
L2.	-.0651882	.0450501	-1.45	0.148	-.1534847	.0231084
w						
--.	-.5257597	.1546107	-3.40	0.001	-.828791	-.2227284
L1.	.3112899	.2030006	1.53	0.125	-.086584	.7091638
k						
--.	.2783619	.0728019	3.82	0.000	.1356728	.4210511
L1.	.0140994	.0924575	0.15	0.879	-.167114	.1953129
L2.	-.0402484	.0432745	-0.93	0.352	-.1250649	.0445681
ys						
--.	.5919243	.1730916	3.42	0.001	.252671	.9311776
L1.	-.5659863	.2611008	-2.17	0.030	-1.077734	-.0542381
L2.	.1005433	.1610987	0.62	0.533	-.2152043	.4162908
yr1980	.0006378	.0168042	0.04	0.970	-.0322978	.0335734
yr1981	-.0550044	.0313389	-1.76	0.079	-.1164275	.0064187
yr1982	-.075978	.0419276	-1.81	0.070	-.1581545	.0061986
yr1983	-.0740708	.0528381	-1.40	0.161	-.1776315	.02949
yr1984	-.0906606	.0642615	-1.41	0.158	-.2166108	.0352896
year	.0112155	.0116783	0.96	0.337	-.0116735	.0341045
_cons	-21.53725	23.23138	-0.93	0.354	-67.06992	23.99542

Instruments for differenced equation

GMM-type: L(2/.)n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980

D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.yr1985

Instruments for level equation

Standard: _cons

Including the constant does not affect the other parameter estimates because it is identified only by the level errors; see [XT] [xtdpd](#) for details.



➤ Example 6: Including predetermined covariates

Sometimes we cannot assume strict exogeneity. Recall that a variable, x_{it} , is said to be strictly exogenous if $E[x_{it}\epsilon_{is}] = 0$ for all t and s . If $E[x_{it}\epsilon_{is}] \neq 0$ for $s < t$ but $E[x_{it}\epsilon_{is}] = 0$ for all $s \geq t$, the variable is said to be predetermined. Intuitively, if the error term at time t has some feedback on the subsequent realizations of x_{it} , x_{it} is a predetermined variable. Because unforecastable errors today might affect future changes in the real wage and in the capital stock, we might suspect that the log of the real product wage and the log of the gross capital stock are predetermined instead of strictly exogenous. Here we treat w and k as predetermined and use lagged levels as instruments.


```
. xtabond n l(0/1).ys yr1980-yr1984 year, lags(2) twostep pre(w, lag(1,.))
> pre(k, lag(2,.)) noconstant vce(robust)

Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                             Number of groups     =      140
Time variable: year

Obs per group:      min =      4
                   avg =  4.364286
                   max =      6

Number of instruments =      83                  Wald chi2(15)        =     958.30
                                                Prob > chi2          =     0.0000

Two-step results

                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.8580958	.1265515	6.78	0.000	.6100594	1.106132
L2.	-.081207	.0760703	-1.07	0.286	-.2303022	.0678881
w						
--.	-.6910855	.1387684	-4.98	0.000	-.9630666	-.4191044
L1.	.5961712	.1497338	3.98	0.000	.3026982	.8896441
k						
--.	.4140654	.1382788	2.99	0.003	.1430439	.6850868
L1.	-.1537048	.1220244	-1.26	0.208	-.3928681	.0854586
L2.	-.1025833	.0710886	-1.44	0.149	-.2419143	.0367477
ys						
--.	.6936392	.1728623	4.01	0.000	.3548354	1.032443
L1.	-.8773678	.2183085	-4.02	0.000	-1.305245	-.449491
yr1980	-.0072451	.017163	-0.42	0.673	-.0408839	.0263938
yr1981	-.0609608	.030207	-2.02	0.044	-.1201655	-.0017561
yr1982	-.1130369	.0454826	-2.49	0.013	-.2021812	-.0238926
yr1983	-.1335249	.0600213	-2.22	0.026	-.2511645	-.0158853
yr1984	-.1623177	.0725434	-2.24	0.025	-.3045001	-.0201352
year	.0264501	.0119329	2.22	0.027	.003062	.0498381

```
Instruments for differenced equation
GMM-type: L(2/.)n L(1/.)L.w L(1/.)L2.k
Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984
          D.year
```

The footer informs us that we are now including GMM-type instruments from the first lag of L.w on back and from the first lag of L2.k on back.

❑ **Technical note**

The above example illustrates that `xtabond` understands `pre(w, lag(1, .))` to mean that L.w is a predetermined variable and `pre(k, lag(2, .))` to mean that L2.k is a predetermined variable. This is a stricter definition than the alternative that `pre(w, lag(1, .))` means only that w is predetermined but includes a lag of w in the model and that `pre(k, lag(2, .))` means only that k is predetermined but includes first and second lags of k in the model. If you prefer the weaker definition, `xtabond` still gives you consistent estimates, but it is not using all possible instruments; see [XT] `xtdpd` for an [example](#) of how to include all possible instruments.

periods held fixed.) The number of instruments increases quadratically in the number of periods. If your dataset is better described by a framework in which both the number of panels and the number of periods is large, then you should consider other estimators such as those in [XT] xtivreg or xtreg, fe in [XT] xtreg; see Alvarez and Arellano (2003) for a discussion of this case.

➤ Example 8: Restricting the number of instruments

Treating variables as predetermined or endogenous quickly increases the size of the instrument matrix. (See *Methods and formulas* in [XT] xtldp for a discussion of how this matrix is created and what determines its size.) GMM estimators with too many overidentifying restrictions may perform poorly in small samples. (See Kiviet 1995 for a discussion of the dynamic panel-data case.)

To handle these problems, you can set a maximum number of lagged levels to be included as instruments for lagged-dependent or the predetermined variables. Here is an example in which a maximum of three lagged levels of the predetermined variables are included as instruments:

```
. xtabond n l(0/1).ys yr1980-yr1984 year, lags(2) twostep
> pre(w, lag(1,3)) pre(k, lag(2,3)) noconstant vce(robust)

Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                             Number of groups       =      140
Time variable: year

Obs per group:      min =      4
                   avg =  4.364286
                   max =      6

Number of instruments =      67                  Wald chi2(15)          =    1116.89
                                                Prob > chi2            =      0.0000

Two-step results

                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.931121	.1456964	6.39	0.000	.6455612	1.216681
L2.	-.0759918	.0854356	-0.89	0.374	-.2434425	.0914589
w						
--.	-.6475372	.1687931	-3.84	0.000	-.9783656	-.3167089
L1.	.6906238	.1789698	3.86	0.000	.3398493	1.041398
k						
--.	.3788106	.1848137	2.05	0.040	.0165824	.7410389
L1.	-.2158533	.1446198	-1.49	0.136	-.4993028	.0675962
L2.	-.0914584	.0852267	-1.07	0.283	-.2584997	.0755829
ys						
--.	.7324964	.176748	4.14	0.000	.3860766	1.078916
L1.	-.9428141	.2735472	-3.45	0.001	-1.478957	-.4066715
yr1980	-.0102389	.0172473	-0.59	0.553	-.0440431	.0235652
yr1981	-.0763495	.0296992	-2.57	0.010	-.1345589	-.0181402
yr1982	-.1373829	.0441833	-3.11	0.002	-.2239806	-.0507853
yr1983	-.1825149	.0613674	-2.97	0.003	-.3027928	-.0622369
yr1984	-.2314023	.0753669	-3.07	0.002	-.3791186	-.083686
year	.0310012	.0119167	2.60	0.009	.0076448	.0543576

```
Instruments for differenced equation
GMM-type: L(2/.)n L(1/3).L.w L(1/3).L2.k
Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984
          D.year
```


► Example 9: Missing observations in the middle of panels

xtabond handles data in which there are missing observations in the middle of the panels. In this example, we deliberately set the dependent variable to missing in the year 1980:

```
. replace n=. if year==1980
(140 real changes made, 140 to missing)

. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) noconstant
> vce(robust)
note: yr1980 dropped from div() because of collinearity
note: yr1981 dropped from div() because of collinearity
note: yr1982 dropped from div() because of collinearity
note: yr1980 dropped because of collinearity
note: yr1981 dropped because of collinearity
note: yr1982 dropped because of collinearity

Arellano-Bond dynamic panel-data estimation      Number of obs      =          115
Group variable: id                               Number of groups     =          101
Time variable: year

Obs per group:      min =           1
                   avg =    1.138614
                   max =           2

Number of instruments =      18                Wald chi2(12)         =      44.48
                                           Prob > chi2           =      0.0000

One-step results
                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.1790577	.2204682	0.81	0.417	-.253052	.6111674
L2.	.0214253	.0488476	0.44	0.661	-.0743143	.1171649
w						
--.	-.2513405	.1402114	-1.79	0.073	-.5261498	.0234689
L1.	.1983952	.1445875	1.37	0.170	-.0849912	.4817815
k						
--.	.3983149	.0883352	4.51	0.000	.2251811	.5714488
L1.	-.025125	.0909236	-0.28	0.782	-.203332	.1530821
L2.	-.0359338	.0623382	-0.58	0.564	-.1581144	.0862468
ys						
--.	.3663201	.3824893	0.96	0.338	-.3833451	1.115985
L1.	-.6319976	.4823958	-1.31	0.190	-1.577476	.3134807
L2.	.5318404	.4105269	1.30	0.195	-.2727775	1.336458
yr1983	-.0047543	.024855	-0.19	0.848	-.0534692	.0439606
yr1984	0	(omitted)				
year	.0014465	.010355	0.14	0.889	-.0188489	.0217419

Instruments for differenced equation

GMM-type: L(2/.)n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1983
D.yr1984 D.year

There are two important aspects to this example. First, xtabond reports that variables have been dropped from the model and from the `div()` instrument list. For xtabond, the `div()` instrument list is the list of instruments created from the strictly exogenous variables; see [\[XT\] xtdpd](#) for more about the `div()` instrument list. Second, because xtabond uses time-series operators in its computations, `if` statements and missing values are not equivalent. An `if` statement causes the false observations to

be excluded from the sample, but it computes the time-series operators wherever possible. In contrast, missing data prevent evaluation of the time-series operators that involve missing observations. Thus the example above is not equivalent to the following one:

```
. use http://www.stata-press.com/data/r13/abdata, clear
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year if year!=1980,
> lags(2) noconstant vce(robust)
note: yr1980 dropped from div() because of collinearity
note: yr1980 dropped because of collinearity

Arellano-Bond dynamic panel-data estimation      Number of obs      =      473
Group variable: id                               Number of groups    =      140
Time variable: year

Obs per group:      min =      3
                   avg =  3.378571
                   max =      5

Number of instruments =      37                Wald chi2(15)       =    1041.61
                                                Prob > chi2         =      0.0000

One-step results
                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.7210062	.1321214	5.46	0.000	.4620531	.9799593
L2.	-.0960646	.0570547	-1.68	0.092	-.2078898	.0157606
w						
--.	-.6684175	.1739484	-3.84	0.000	-1.00935	-.3274849
L1.	.482322	.1647185	2.93	0.003	.1594797	.8051642
k						
--.	.3802777	.0728546	5.22	0.000	.2374853	.5230701
L1.	-.104598	.088597	-1.18	0.238	-.278245	.069049
L2.	-.0272055	.0379994	-0.72	0.474	-.101683	.0472721
ys						
--.	.4655989	.1864368	2.50	0.013	.1001895	.8310082
L1.	-.8562492	.2187886	-3.91	0.000	-1.285067	-.4274315
L2.	.0896556	.1440035	0.62	0.534	-.192586	.3718972
yr1981	-.0711626	.0205299	-3.47	0.001	-.1114005	-.0309247
yr1982	-.1212749	.0334659	-3.62	0.000	-.1868669	-.0556829
yr1983	-.1470248	.0461714	-3.18	0.001	-.2375191	-.0565305
yr1984	-.1519021	.0543904	-2.79	0.005	-.2585054	-.0452988
year	.0203277	.0108732	1.87	0.062	-.0009833	.0416387

Instruments for differenced equation
GMM-type: L(2/.)n
Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1981
D.yr1982 D.yr1983 D.yr1984 D.year

The year 1980 is dropped from the sample, but when the value of a variable from 1980 is required because a lag or difference is required, the 1980 value is used.



Stored results

xtabond stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	χ^2
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of σ_ϵ^2
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

Macros

<code>e(cmd)</code>	xtabond
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(twostep)</code>	twostep, if specified
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(system)</code>	system, if system estimator
<code>e(hascons)</code>	hascons, if specified
<code>e(transform)</code>	specified transform
<code>e(diffvars)</code>	already differenced variables
<code>e(datasignature)</code>	checksum from <i>datasignature</i>
<code>e(properties)</code>	b V
<code>e(estat_cmd)</code>	program used to implement <i>estat</i>
<code>e(predict)</code>	program used to implement <i>predict</i>
<code>e(marginsok)</code>	predictions allowed by <i>margins</i>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

A dynamic panel-data model has the form

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it} \beta_1 + \mathbf{w}_{it} \beta_2 + \nu_i + \epsilon_{it} \quad i = 1, \dots, N \quad t = 1, \dots, T_i \quad (1)$$

where

the α_j are p parameters to be estimated,
 \mathbf{x}_{it} is a $1 \times k_1$ vector of strictly exogenous covariates,
 β_1 is a $k_1 \times 1$ vector of parameters to be estimated,
 \mathbf{w}_{it} is a $1 \times k_2$ vector of predetermined and endogenous covariates,
 β_2 is a $k_2 \times 1$ vector of parameters to be estimated,
 ν_i are the panel-level effects (which may be correlated with the covariates), and
 ϵ_{it} are i.i.d. over the whole sample with variance σ_ϵ^2 .

The ν_i and the ϵ_{it} are assumed to be independent for each i over all t .

By construction, the lagged dependent variables are correlated with the unobserved panel-level effects, making standard estimators inconsistent. With many panels and few periods, estimators are constructed by first-differencing to remove the panel-level effects and using instruments to form moment conditions.

`xtabond` uses a GMM estimator to estimate $\alpha_1, \dots, \alpha_p, \beta_1$, and β_2 . The moment conditions are formed from the first-differenced errors from (1) and instruments. Lagged levels of the dependent variable, the predetermined variables, and the endogenous variables are used to form GMM-type instruments. See [Arellano and Bond \(1991\)](#) and [Holtz-Eakin, Newey, and Rosen \(1988\)](#) for discussions of GMM-type instruments. First differences of the strictly exogenous variables are used as standard instruments.

`xtabond` uses `xtdpd` to perform its computations, so the formulas are given in [Methods and formulas](#) of [\[XT\] xtdpd](#).

References

- Alvarez, J., and M. Arellano. 2003. The time series and cross-section asymptotics of dynamic panel data estimators. *Econometrica* 71: 1121–1159.
- Anderson, T. W., and C. Hsiao. 1981. Estimation of dynamic models with error components. *Journal of the American Statistical Association* 76: 598–606.
- . 1982. Formulation and estimation of dynamic models using panel data. *Journal of Econometrics* 18: 47–82.
- Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.
- Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Blackburne, E. F., III, and M. W. Frank. 2007. Estimation of nonstationary heterogeneous panels. *Stata Journal* 7: 197–208.
- Bruno, G. S. F. 2005. Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *Stata Journal* 5: 473–500.
- Hansen, L. P. 1982. Large sample properties of generalized method of moments estimators. *Econometrica* 50: 1029–1054.
- Holtz-Eakin, D., W. K. Newey, and H. S. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* 56: 1371–1395.
- Kiviet, J. F. 1995. On bias, inconsistency, and efficiency of various estimators in dynamic panel data models. *Journal of Econometrics* 68: 53–78.
- Layard, R., and S. J. Nickell. 1986. Unemployment in Britain. *Economica* 53: S121–S169.
- Windmeijer, F. 2005. A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics* 126: 25–51.

Also see

- [XT] **xtabond postestimation** — Postestimation tools for xtabond
- [XT] **xtset** — Declare data to be panel data
- [XT] **xtdpd** — Linear dynamic panel-data estimation
- [XT] **xtdpdsys** — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [U] **20 Estimation and postestimation commands**

Description	Syntax for predict	Menu for predict
Options for predict	Syntax for estat	Menu for estat
Option for estat abond	Remarks and examples	Methods and formulas
Also see		

Description

The following postestimation commands are of special interest after `xtabond`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Special-interest postestimation commands

- `estat abond` reports the Arellano–Bond tests for serial correlation in the first-differenced errors.
- `estat sargan` reports the Sargan test of the overidentifying restrictions.

Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

e calculates the residual error.

stdp calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. **stdp** may not be combined with **difference**.

difference specifies that the statistic be calculated for the first differences instead of the levels, the default.

Syntax for estat

Test for autocorrelation

```
estat abond [, artests(#)]
```

Sargan test of overidentifying restrictions

```
estat sargan
```

Menu for estat

Statistics > Postestimation > Reports and statistics

Option for estat abond

artests(#) specifies the highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when **artests(#)** specifies a higher order than that computed during the original estimation. The model can be refit only if the data have not changed.

Remarks and examples

Remarks are presented under the following headings:

estat abond
estat sargan

estat abond

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced errors at order m . Rejecting the null hypothesis of no serial correlation in the first-differenced errors at order zero does not imply model misspecification because the first-differenced errors are serially correlated if the idiosyncratic errors are independent and identically distributed. Rejecting the null hypothesis of no serial correlation in the first-differenced errors at an order greater than one implies model misspecification; see [example 5](#) in [\[XT\] xtdpd](#) for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified. (The system estimator is used to estimate the constant in `xtabond`.)

See [Remarks and examples](#) in [\[XT\] xtabond](#) for more remarks about `estat abond` that are made in the context of the examples analyzed therein.

estat sargan

The distribution of the Sargan test is known only when the errors are independently and identically distributed. For this reason, `estat sargan` does not produce a test statistic when `vce(robust)` was specified in the call to `xtabond`.

See [Remarks and examples](#) in [\[XT\] xtabond](#) for more remarks about `estat sargan` that are made in the context of the examples analyzed therein.

Methods and formulas

See [\[XT\] xtdpd postestimation](#) for the formulas.

Also see

[\[XT\] xtabond](#) — Arellano–Bond linear dynamic panel-data estimation

[\[U\] 20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options for RE model
Options for PA model	Remarks and examples	Stored results	Methods and formulas
References	Also see		

Syntax

Random-effects (RE) model

xtcloglog *depvar* [*indepvars*] [*if*] [*in*] [*weight*] [, re *RE_options*]

Population-averaged (PA) model

xtcloglog *depvar* [*indepvars*] [*if*] [*in*] [*weight*], pa [*PA_options*]

<i>RE_options</i>	Description
Model	
<u>no</u> constant	suppress constant term
re	use random-effects estimator; the default
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
asis	retain perfect predictor variables
SE/Robust	
vce(<i>vcetype</i>)	<i>vcetype</i> may be oim, <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>eform</u>	report exponentiated coefficients
<u>nocnsreport</u>	do not display constraints
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mv</u> aghermite (the default) or <u>gh</u> ermite
<u>intpoints</u> (#)	use # quadrature points; default is intpoints(12)
Maximization	
<i>maximize_options</i>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>asis</u>	retain perfect predictor variables
Correlation	
<u>corr</u> (<i>correlation</i>)	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <code>conventional</code> , <code>robust</code> , <code>bootstrap</code> , or <code>jackknife</code>
<u>nmp</u>	use divisor $N - P$ instead of the default N
<u>scale</u> (<i>parm</i>)	overrides the default scale parameter; <i>parm</i> may be <code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code>
Reporting	
<u>level</u> (<i>#</i>)	set confidence level; default is <code>level(95)</code>
<u>eform</u>	report exponentiated coefficients
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable; the default
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> <i>#</i>	autoregressive of order <i>#</i>
<u>stationary</u> <i>#</i>	stationary of order <i>#</i>
<u>nonstationary</u> <i>#</i>	nonstationary of order <i>#</i>

A panel variable must be specified. For `xtcloglog`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

`indepsvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands. `fp` is allowed for the random-effects model.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`weights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `weights` are allowed for the random-effects model; see [U] 11.1.6 weight. Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Binary outcomes > Complementary log-log regression (RE, PA)

Description

`xtcloglog` fits population-averaged and random-effects complementary log-log (cloglog) models. There is no command for a conditional fixed-effects model, as there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood. Unconditional fixed-effects cloglog models may be fit with `cloglog` with indicator variables for the panels. However, unconditional fixed-effects estimates are biased.

By default, the population-averaged model is an equal-correlation model; that is, `xtcloglog`, `pa` assumes `corr(exchangeable)`. See [XT] [xtgee](#) for information on fitting other population-averaged models.

See [R] [logistic](#) for a list of related estimation commands.

Options for RE model

Model

`noconstant`; see [R] [estimation options](#).

`re` requests the random-effects estimator, which is the default.

`offset(varname)`, `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtcloglog, re and the robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`, `noskip`; see [R] [estimation options](#).

`eform` displays the exponentiated coefficients and corresponding standard errors and confidence intervals.

`nocnsreport`; see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no!stretch`; see [R] [estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtcloglog` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator.

`offset(varname)`; see [R] [estimation options](#)

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`eform` displays the exponentiated coefficients and corresponding standard errors and confidence intervals.

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Optimization

optimize_options control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtcloglog` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtcloglog`, `pa` is a shortcut command for fitting the population-averaged model. Typing

```
. xtcloglog ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(cloglog) corr(exchangeable)
```

Also see [XT] [xtgee](#) for information about `xtcloglog`.

By default or when `re` is specified, `xtcloglog` fits, via maximum likelihood, the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = P(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, ν_i are i.i.d., $N(0, \sigma_\nu^2)$, and $P(z) = 1 - \exp\{-\exp(z)\}$.

Underlying this model is the variance-components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} > 0$$

where ϵ_{it} are i.i.d. extreme-value (Gumbel) distributed with the mean equal to Euler's constant and variance $\sigma_\epsilon^2 = \pi^2/6$, independently of ν_i . The nonsymmetric error distribution is an alternative to logit and probit analysis and is typically used when the positive (or negative) outcome is rare.

➤ Example 1

Suppose that we are studying unionization of women in the United States and are using the union dataset; see [XT] xt. We wish to fit a random-effects model of union membership:

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtcloglog union age grade not_smsa south##c.year
(output omitted)
Random-effects complementary log-log model      Number of obs      =      26200
Group variable: idcode                        Number of groups    =      4434
Random effects u_i ~ Gaussian                  Obs per group: min =          1
                                                avg =          5.9
                                                max =          12
Integration method: mvaghermite                Integration points =          12
Wald chi2(6) =      248.58
Prob > chi2 =      0.0000
Log likelihood = -10535.928
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0128659	.0119004	1.08	0.280	-.0104586	.0361903
grade	.06985	.0138135	5.06	0.000	.042776	.096924
not_smsa	-.198416	.0647943	-3.06	0.002	-.3254104	-.0714215
1.south	-2.047645	.488965	-4.19	0.000	-3.005999	-1.089291
year	-.0006432	.0123569	-0.05	0.958	-.0248623	.0235759
south#c.year						
1	.0164259	.006065	2.71	0.007	.0045387	.0283132
_cons	-3.269158	.659029	-4.96	0.000	-4.560831	-1.977485
/lnsig2u	1.24128	.0461705			1.150787	1.331772
sigma_u	1.860118	.0429413			1.77783	1.946214
rho	.677778	.0100834			.6577057	.6972152

Likelihood-ratio test of rho=0: chibar2(01) = 6009.36 Prob >= chibar2 = 0.000

The output includes the additional panel-level variance component, which is parameterized as the log of the standard deviation, $\ln\sigma_\nu$ (labeled `lnsig2u` in the output). The standard deviation σ_ν is also included in the output, labeled `sigma_u`, together with ρ (labeled `rho`),

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + \sigma_\epsilon^2}$$

which is the proportion of the total variance contributed by the panel-level variance component. When `rho` is zero, the panel-level variance component is not important, and the panel estimator is no different from the pooled estimator (`cloglog`). A likelihood-ratio test of this is included at the bottom of the output, which formally compares the pooled estimator with the panel estimator.

As an alternative to the random-effects specification, you might want to fit an equal-correlation population-averaged cloglog model by typing

```
. xtcloglog union age grade not_smsa south##c.year, pa
Iteration 1: tolerance = .11878399
Iteration 2: tolerance = .01424628
Iteration 3: tolerance = .00075278
Iteration 4: tolerance = .00003195
Iteration 5: tolerance = 1.661e-06
Iteration 6: tolerance = 8.308e-08

GEE population-averaged model
Group variable:          idcode      Number of obs      =      26200
Link:                  cloglog      Number of groups   =      4434
Family:                binomial      Obs per group: min =          1
Correlation:           exchangeable      avg =          5.9
                                      max =          12
Scale parameter:          1      Wald chi2(6)         =      234.66
                                      Prob > chi2          =      0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0153737	.0081156	1.89	0.058	-.0005326	.03128
grade	.0549518	.0095093	5.78	0.000	.0363139	.0735897
not_smsa	-.1045232	.0431082	-2.42	0.015	-.1890138	-.0200326
1.south	-1.714868	.3384558	-5.07	0.000	-2.378229	-1.051507
year	-.0115881	.0084125	-1.38	0.168	-.0280763	.0049001
south#c.year						
1	.0149796	.0041687	3.59	0.000	.0068091	.0231501
_cons	-1.488278	.4468005	-3.33	0.001	-2.363991	-.6125652

◀

► Example 2

In [R] [cloglog](#), we showed these results and compared them with `cloglog`, `vce(cluster id)`. `xtcloglog` with the `pa` option allows a `vce(robust)` option (the random-effects estimator does not allow the `vce(robust)` specification), so we can obtain the population-averaged cloglog estimator with the robust variance calculation by typing


```
. xtcloglog union age grade not_smsa south##c.year, pa vce(robust)
(output omitted)

GEE population-averaged model
Group variable:          idcode      Number of obs      =      26200
Link:                   cloglog      Number of groups   =      4434
Family:                 binomial     Obs per group: min =          1
Correlation:            exchangeable          avg =         5.9
                                      max =         12
                                      Wald chi2(6)      =      157.24
Scale parameter:        1           Prob > chi2        =      0.0000
                                   (Std. Err. adjusted for clustering on idcode)
```

union	Semirobust		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
age	.0153737	.0079446	1.94	0.053	-.0001974	.0309448
grade	.0549518	.0117258	4.69	0.000	.0319697	.077934
not_smsa	-.1045232	.0548598	-1.91	0.057	-.2120465	.0030001
1.south	-1.714868	.4864999	-3.52	0.000	-2.66839	-.7613455
year	-.0115881	.0085742	-1.35	0.177	-.0283932	.005217
south#c.year						
1	.0149796	.0060548	2.47	0.013	.0031124	.0268468
_cons	-1.488278	.4924738	-3.02	0.003	-2.453509	-.5230472

These standard errors are similar to those shown for `cloglog`, `vce(cluster id)` in [\[R\] cloglog](#). ◀

❏ **Technical note**

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [\[XT\] quadchk](#) for details and [\[XT\] xtprobit](#) for an [example](#).

Because the `xtcloglog` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature. ❏

Stored results

xtcloglog, re stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	ρ
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtcloglog</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

xtcloglog, pa stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(df_pear)</code>	degrees of freedom for Pearson χ^2
<code>e(chi2_dev)</code>	χ^2 test of deviance
<code>e(chi2_dis)</code>	χ^2 test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	xtgee
<code>e(cmd2)</code>	xtcloglog
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	pa
<code>e(family)</code>	binomial
<code>e(link)</code>	cloglog; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	x2, dev, phi, or #, scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	vctype specified in <code>vce()</code>
<code>e(vctype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	nmp, if specified
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsnotok)</code>	predictions disallowed by margins
<code>e(asbalanced)</code>	factor variables fvset as asbalanced
<code>e(asobserved)</code>	factor variables fvset as asobserved

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

xtcloglog, pa reports the population-averaged results obtained using xtgee, family(binomial) link(cloglog) to obtain estimates.

For the random-effects model, assume a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i ,

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} 1 - \exp\{-\exp(z)\} & \text{if } y \neq 0 \\ \exp\{-\exp(z)\} & \text{otherwise} \end{cases}$$

The panel-level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, with the definition of $g(y_{it}, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right]$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of $1e-6$; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where $\rho = \sigma_\nu^2/(\sigma_\nu^2 + 1)$:

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

xtcloglog, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Neuhaus, J. M., J. D. Kalbfleisch, and W. W. Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59: 25–35.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtcloglog postestimation** — Postestimation tools for xtcloglog
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **mecloglog** — Multilevel mixed-effects complementary log-log regression
- [MI] **estimation** — Estimation commands for use with mi estimate
- [R] **cloglog** — Complementary log-log regression
- [U] **20 Estimation and postestimation commands**

Description

The following postestimation commands are available after `xtcloglog`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtcloglog`, `pa`.
² `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

Random-effects (RE) model

```
predict [type] newvar [if] [in] [, RE_statistic nooffset]
```

Population-averaged (PA) model

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```


<i>RE_statistic</i>	Description
Main	
<code>xb</code>	linear prediction; the default
<code>pu0</code>	probability of a positive outcome
<code>stdp</code>	standard error of the linear prediction

<i>PA_statistic</i>	Description
Main	
<code>mu</code>	predicted probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted probability of <i>depvar</i>
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- `xb` calculates the linear prediction. This is the default for the random-effects model.
- `pu0` calculates the probability of a positive outcome, assuming that the random effect for that observation's panel is zero ($\nu = 0$). This may not be similar to the proportion of observed outcomes in the group.
- `stdp` calculates the standard error of the linear prediction.
- `mu` and `rate` both calculate the predicted probability of *depvar*. `mu` takes into account the `offset()`. `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.
- `score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\beta) / \partial (\mathbf{x}_j\beta)$.
- `nooffset` is relevant only if you specified `offset(varname)` for `xtcloglog`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [\[XT\] xtcloglog](#), we fit the model

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtcloglog union age grade not_smsa south##c.year, pa
(output omitted)
```

Here we use `margins` to determine the average effect each regressor has on the probability of a positive response in the sample.

```
. margins, dydx(*)
Average marginal effects              Number of obs   =      26200
Model VCE      : Conventional
Expression    : Pr(union != 0), predict()
dy/dx w.r.t.  : age grade not_smsa 1.south year
```

	Delta-method		z	P> z	[95% Conf. Interval]	
	dy/dx	Std. Err.				
age	.0028297	.0014952	1.89	0.058	-.000101	.0057603
grade	.0101144	.0017498	5.78	0.000	.0066848	.013544
not_smsa	-.0192384	.0079304	-2.43	0.015	-.0347818	-.0036951
1.south	-.0913197	.0073101	-12.49	0.000	-.1056473	-.0769921
year	-.0012694	.001534	-0.83	0.408	-.004276	.0017371

Note: dy/dx for factor levels is the discrete change from the base level.

We see that an additional year of schooling (covariate `grade`) increases the probability that a woman belongs to a union by an average of about one percentage point.



Also see

[\[XT\] xtcloglog](#) — Random-effects and population-averaged cloglog models

[\[U\] 20 Estimation and postestimation commands](#)

Syntax

xtdata [*varlist*] [*if*] [*in*] [, *options*]

<i>options</i>	Description
Main	
re	convert data to a form suitable for random-effects estimation
ratio(#)	ratio of random effect to pure residual (standard deviations)
be	convert data to a form suitable for between estimation
fe	convert data to a form suitable for fixed-effects (within) estimation
nodouble	keep original variable type; default is to recast type as double
clear	overwrite current data in memory

A panel variable must be specified; use `xtset`; see [\[XT\] xtset](#).

Menu

Statistics > Longitudinal/panel data > Setup and utilities > Faster specification searches with xt data

Description

`xtdata` produces a transformed dataset of the variables specified in *varlist* or of all the variables in the data. Once the data are transformed, Stata’s `regress` command may be used to perform specification searches more quickly than `xtreg`; see [\[R\] regress](#) and [\[XT\] xtreg](#). Using `xtdata`, `re` also creates a variable named `constant`. When using `regress` after `xtdata`, `re`, specify `noconstant` and include `constant` in the regression. After `xtdata`, `be` and `xtdata`, `fe`, you need not include `constant` or specify `regress`’s `noconstant` option.

Options

Main

- `re` specifies that the data are to be converted into a form suitable for random-effects estimation. `re` is the default if `be`, `fe`, or `re` is not specified. `ratio()` must also be specified.
- `ratio(#)` (use with `xtdata`, `re` only) specifies the ratio σ_v/σ_ϵ , which is the ratio of the random effect to the pure residual. This is the ratio of the standard deviations, not the variances.
- `be` specifies that the data are to be converted into a form suitable for between estimation.
- `fe` specifies that the data are to be converted into a form suitable for fixed-effects (within) estimation.

`nodouble` specifies that transformed variables keep their original types, if possible. The default is to recast variables to `double`.

Remember that `xtdata` transforms variables to be differences from group means, pseudodifferences from group means, or group means. Specifying `nodouble` will decrease the size of the resulting dataset but may introduce roundoff errors in these calculations.

`clear` specifies that the data may be converted even though the dataset has changed since it was last saved on disk.

Remarks and examples

If you have not read [XT] `xt` and [XT] `xtreg`, please do so.

The formal estimation commands of `xtreg`—see [XT] `xtreg`—do not produce results instantaneously, especially with large datasets. Equations (2), (3), and (4) of [XT] `xtreg` describe the data necessary to fit each of the models with OLS. The idea here is to transform the data once to the appropriate form and then use `regress` to fit such models more quickly.

➤ Example 1

We will use the [example](#) in [XT] `xtreg` demonstrating between-effects regression. Another way to estimate the between equation is to convert the data in memory to the between data:

```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. generate age2=age^2
(24 missing values generated)
. generate ttl_exp2 = ttl_exp^2
. generate tenure2=tenure^2
(433 missing values generated)
. generate byte black = race==2
. xtdata ln_w grade age* ttl_exp* tenure* black not_smsa south, be clear
. regress ln_w grade age* ttl_exp* tenure* black not_smsa south
```

Source	SS	df	MS	Number of obs = 4697		
Model	415.021613	10	41.5021613	F(10, 4686) = 450.23		
Residual	431.954995	4686	.092179896	Prob > F = 0.0000		
				R-squared = 0.4900		
				Adj R-squared = 0.4889		
Total	846.976608	4696	.180361288	Root MSE = .30361		

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	.0607602	.0020006	30.37	0.000	.0568382	.0646822
age	.0323158	.0087251	3.70	0.000	.0152105	.0494211
age2	-.0005997	.0001429	-4.20	0.000	-.0008799	-.0003194
(output omitted)						
south	-.0993378	.010136	-9.80	0.000	-.1192091	-.0794665
_cons	.3339113	.1210434	2.76	0.006	.0966093	.5712133

The output is the same as that produced by `xtreg, be`; the reported R^2 is the R^2 between. Using `xtdata` followed by just one `regress` does not save time. Using `xtdata` is justified when you intend to explore the specification of the model by running many alternative regressions.

□ Technical note

When using `xtdata`, you must eliminate any variables that you do not intend to use and that have missing values. `xtdata` follows a casewise-deletion rule, which means that an observation is excluded from the conversion if it is missing on any of the variables. In the [example above](#), we specified that the variables be converted on the command line. We could also drop the variables first, and it might even be useful to preserve our estimation sample:

```
. use http://www.stata-press.com/data/r13/nlswork, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. generate age2=age^2
(24 missing values generated)
. generate ttl_exp2 = ttl_exp^2
. generate tenure2=tenure^2
(433 missing values generated)
. generate byte black = race==2
. keep id year ln_w grade age* ttl_exp* tenure* black not_smsa south
. save xtdataimpl
file xtdataimpl.dta saved
```

□

▷ Example 2

`xtdata` with the `fe` option converts the data so that results are equivalent to those from estimating by using `xtreg` with the `fe` option.

```
. xtdata, fe
. regress ln_w grade age* ttl_exp* tenure* black not_smsa south
note: grade omitted because of collinearity
note: black omitted because of collinearity
```

Source	SS	df	MS	Number of obs =	28091
Model	412.443881	8	51.5554852	F(8, 28082) =	732.64
Residual	1976.12232	28082	.070369714	Prob > F =	0.0000
				R-squared =	0.1727
				Adj R-squared =	0.1724
Total	2388.5662	28090	.085032617	Root MSE =	.26527

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	0	(omitted)				
age	.0359987	.0030903	11.65	0.000	.0299415	.0420558
age2	-.000723	.0000486	-14.88	0.000	-.0008183	-.0006277
ttl_exp	.0334668	.0027061	12.37	0.000	.0281627	.0387708
ttl_exp2	.0002163	.0001166	1.86	0.064	-.0000122	.0004447
tenure	.0357539	.0016871	21.19	0.000	.0324472	.0390606
tenure2	-.0019701	.0001141	-17.27	0.000	-.0021937	-.0017465
black	0	(omitted)				
not_smsa	-.0890108	.0086982	-10.23	0.000	-.1060597	-.0719619
south	-.0606309	.0099761	-6.08	0.000	-.0801845	-.0410772
_cons	1.03732	.0443093	23.41	0.000	.9504716	1.124168

The coefficients reported by `regress` after `xtdata, fe` are the same as those reported by `xtreg, fe`, but the standard errors are slightly smaller. This is because no adjustment has been made to the estimated covariance matrix for the estimation of the person means. The difference is small, however, and results are adequate for a specification search.

◀

➤ **Example 3**

To use `xtdata`, `re`, you must specify the ratio σ_v/σ_ϵ , which is the ratio of the standard deviations of the random effect and pure residual. Merely to show the relationship of `regress` after `xtdata`, `re` to `xtreg`, `re`, we will specify this ratio as $0.25790526/0.29068923 = 0.88721987$, which is the number `xtreg` reports when the model is fit from the outset; see the [random-effects example in \[XT\] xtreg](#). For specification searches, however, it is adequate to specify this number more crudely, and, when performing the specification search for this manual entry, we used `ratio(1)`.

```
. use http://www.stata-press.com/data/r13/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtdata, clear re ratio(.88721987)
```

		theta		
min	5%	median	95%	max
0.2520	0.2520	0.5499	0.7016	0.7206

`xtdata` reports the distribution of θ based on the specified ratio. If these were balanced data, θ would have been constant.

When running regressions with these data, you must specify the `noconstant` option and include the variable `constant`:

```
. regress ln_w grade age* ttl_exp* tenure* black not_smsa south constant,
> noconstant
```

Source	SS	df	MS	Number of obs = 28091		
Model	13271.7208	11	1206.52007	F(11, 28080) =14302.56		
Residual	2368.74223	28080	.084356917	Prob > F = 0.0000		
				R-squared = 0.8486		
				Adj R-squared = 0.8485		
Total	15640.463	28091	.556778435	Root MSE = .29044		

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	.0646499	.0017812	36.30	0.000	.0611587	.0681411
age	.0368059	.0031195	11.80	0.000	.0306915	.0429203
age2	-.0007133	.00005	-14.27	0.000	-.0008113	-.0006153
(output omitted)						
south	-.0868922	.0073032	-11.90	0.000	-.1012068	-.0725775
constant	.2387206	.049469	4.83	0.000	.141759	.3356822

Results are the same coefficients and standard errors that `xtreg`, `re` estimated in [example 4](#) of [\[XT\] xtreg](#). The summaries at the top, however, should be ignored, as they are expressed in terms of (4) of [\[XT\] xtreg](#), and, moreover, for a model without a constant.

❑ **Technical note**

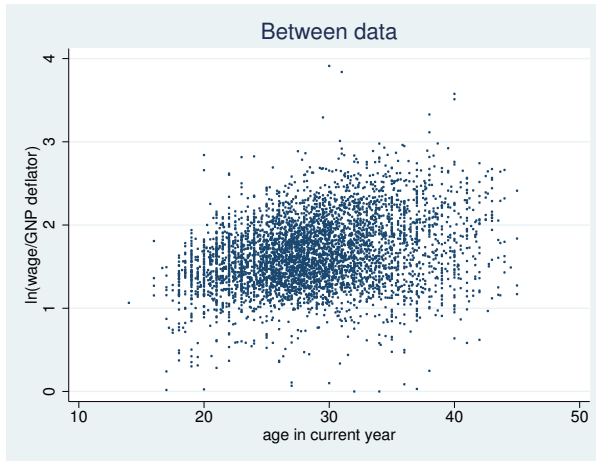
- Using `xtdata` requires some caution. The following guidelines may help:
1. `xtdata` is intended for use only during the specification search phase of analysis. Results should be estimated with `xtreg` on unconverted data.
 2. After converting the data, you may use `regress` to obtain estimates of the coefficients and their standard errors. For `regress` after `xtdata`, `fe`, the standard errors are too small, but only slightly.
 3. You may loosely interpret the coefficient's significance tests and confidence intervals. However, for results after `xtdata`, `fe` and `re`, an incorrect (but close to correct) distribution is assumed.

4. You should ignore the summary statistics reported at the top of `regress`'s output.
5. After converting the data, you may form linear, but not nonlinear, combinations of regressors; that is, if your data contained age, it would not be correct to convert the data and then form age squared. All nonlinear transformations should be done before conversion. (For `xtdata, be`, you can get away with forming nonlinear combinations ex post, but the results will not be exact.) □

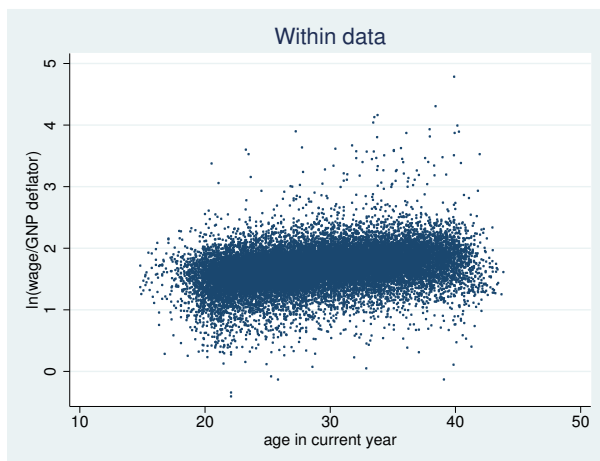
□ Technical note

The `xtdata` command can be used to help you examine data, especially with `scatter`.

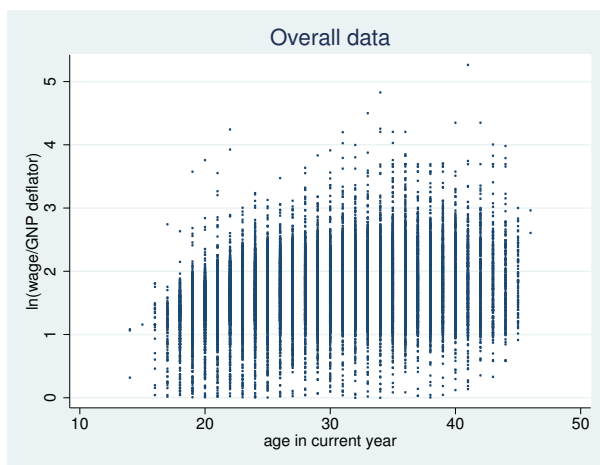
```
. use http://www.stata-press.com/data/r13/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtdata, be
. scatter ln_wage age, title(Between data) msymbol(o) msize(tiny)
```




```
. use http://www.stata-press.com/data/r13/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtdata, fe
. scatter ln_wage age, title(Within data) msymbol(o) msize(tiny)
```



```
. use http://www.stata-press.com/data/r13/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. scatter ln_wage age, title(Overall data) msymbol(o) msize(tiny)
```



Methods and formulas

(This section is a continuation of the *Methods and formulas* of [XT] **xtreg**.)

xtdata, **be**, **fe**, and **re** transform the data according to (2), (3), and (4), respectively, of [XT] **xtreg**, except that **xtdata**, **fe** adds back in the overall mean, thus forming the transformation

$$\mathbf{x}_{it} - \bar{x}_i + \bar{\bar{x}}$$

xtdata, **re** requires the user to specify r as an estimate of $\sigma_\nu/\sigma_\epsilon$. θ_i is calculated from

$$\theta_i = 1 - \frac{1}{\sqrt{T_i r^2 + 1}}$$

Also see

[XT] **xtsum** — Summarize xt data

Syntax

```
xtdescribe [if] [in] [, options]
```

<i>options</i>	Description
Main	
<u>p</u> atterns(<i>#</i>)	maximum participation patterns; default is patterns(9)
<u>w</u> idth(<i>#</i>)	display # width of participation patterns; default is width(100)
A panel variable and a time variable must be specified; use xtset; see [XT] xtset. by is allowed; see [D] by.	

Menu

Statistics > Longitudinal/panel data > Setup and utilities > Describe pattern of xt data

Description

xtdescribe describes the participation pattern of cross-sectional time-series (xt) data.

Options

Main

patterns(*#*) specifies the maximum number of participation patterns to be reported; patterns(9) is the default. Specifying patterns(50) would list up to 50 patterns. Specifying patterns(1000) is taken to mean patterns(∞); all the patterns will be listed.

width(*#*) specifies the desired width of the participation patterns to be displayed; width(100) is the default. If the number of times is greater than width(), then each column in the participation pattern represents multiple periods as indicated in a footnote at the bottom of the table. The actual width may differ slightly from the requested width depending on the span of the time variable and the number of periods.

Remarks and examples

If you have not read [XT] xt, please do so.

xtdescribe describes the cross-sectional and time-series aspects of the data in memory.

➤ Example 1

In [XT] `xt`, we introduced data based on a subsample of the NLSY data on young women aged 14–26 years in 1968. Here is a description of the data used in many of the [XT] `xt` examples:

```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. xtdescribe
    idcode:  1, 2, ..., 5159                      n =          4711
    year:    68, 69, ..., 88                      T =           15
            Delta(year) = 1 unit
            Span(year)  = 21 periods
            (idcode*year uniquely identifies each observation)

Distribution of Ti:
    min      5%      25%      50%      75%      95%      max
      1         1         3         5         9        13        15

    Freq.  Percent  Cum. | Pattern
-----|-----
    136     2.89    2.89 | 1.....
    114     2.42    5.31 | .....1
     89     1.89    7.20 | .....1.11
     87     1.85    9.04 | .....11
     86     1.83   10.87 | 111111.1.11.1.11.11
     61     1.29   12.16 | .....11.1.11
     56     1.19   13.35 | 11.....
     54     1.15   14.50 | .....1.1.11
     54     1.15   15.64 | .....1.11.1.11.11
    3974    84.36  100.00 | (other patterns)

    4711    100.00 | XXXXXX.X.XX.X.XX.X.XX
```

`xtdescribe` tells us that we have 4,711 women in our data and that the `idcode` that identifies each ranges from 1 to 5,159. We are also told that the maximum number of individual years over which we observe any woman is 15, though the `year` variable spans 21 years. The delta or periodicity of `year` is one unit, meaning that in principle we could observe each woman yearly. We are reassured that `idcode` and `year`, taken together, uniquely identify each observation in our data. We are also shown the distribution of T_i ; 50% of our women are observed 5 years or less. Only 5% of our women are observed for 13 years or more.

Finally, we are shown the participation pattern. A 1 in the pattern means one observation that year; a dot means no observation. The largest fraction of our women (still only 2.89%) was observed in the single year 1968 and not thereafter; the next largest fraction was observed in 1988 but not before; and the next largest fraction was observed in 1985, 1987, and 1988.

At the bottom is the sum of the participation patterns, including the patterns that were not shown. We can see that none of the women were observed in six of the years (there are six dots). (The survey was not administered in those six years.)

We could see more of the patterns by specifying the `patterns()` option, or we could see all the patterns by specifying `patterns(1000)`.



➤ Example 2

The strange participation patterns shown above have to do with our subsampling of the data, not with the administrators of the survey. Here are the data from which we drew the sample used in the [XT] `xt` examples:


```
. xtdescribe
```

idcode:	1, 2, ..., 5159	n =	5159
year:	68, 69, ..., 88	T =	15
Delta(year) = 1; (88-68)+1 = 21			
(idcode*year does not uniquely identify observations)			

Distribution of T_i:	min	5%	25%	50%	75%	95%	max
	1	2	11	15	16	19	30

Freq.	Percent	Cum.	Pattern
1034	20.04	20.04	111111.1.11.1.11.1.11
153	2.97	23.01	1.....
147	2.85	25.86	112111.1.11.1.11.1.11
130	2.52	28.38	111112.1.11.1.11.1.11
122	2.36	30.74	111211.1.11.1.11.1.11
113	2.19	32.93	11.....
84	1.63	34.56	111111.1.11.1.11.1.12
79	1.53	36.09	111111.1.12.1.11.1.11
67	1.30	37.39	111111.1.11.1.11.1.1.
3230	62.61	100.00	(other patterns)
5159	100.00		XXXXXX.X.XX.X.XX.X.XX

We have multiple observations per year. In the pattern, 2 indicates that a woman appears twice in the year, 3 indicates 3 times, and so on—X indicates 10 or more, should that be necessary.

In fact, this is a dataset that was itself extracted from the NLSY, in which t is not time but job number. To simplify exposition, we made a simpler dataset by selecting the last job in each year.

► Example 3

When the number of periods is greater than the width of the participation pattern, each column will represent more than one period.

[illegible]

We have data for 30 patients who were observed hourly between 4:00 PM on March 9, 2007, and 11:00 PM on March 10, a span of 32 hours. We have complete records for 21 of the patients. The footnote indicates that each column in the pattern represents two periods, so for four patients we

have an observation taken at either 4:00 PM or 5:00 PM on March 9, but we do not have observations for both times. There are three patients for whom we are missing both the 10:00 PM and 11:00 PM observations on March 10, and there are two patients for whom we are missing the 4:00 PM and 5:00 PM observations for March 9.



Reference

Cox, N. J. 2007. [Speaking Stata: Counting groups, especially panels](#). *Stata Journal* 7: 571–581.

Also see

[XT] [xtsum](#) — Summarize xt data

[XT] [xttab](#) — Tabulate xt data

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	Acknowledgment
References	Also see		

Syntax

```
xtdpd depvar [indepvars] [if] [in], dgmmiv(varlist [...] ) [options]
```

<i>options</i>	Description
Model	
* <u>d</u> gmmiv(<i>varlist</i> [...])	GMM-type instruments for the difference equation; can be specified more than once
<u>l</u> gmmiv(<i>varlist</i> [...])	GMM-type instruments for the level equation; can be specified more than once
iv(<i>varlist</i> [...])	standard instruments for the difference and level equations; can be specified more than once
div(<i>varlist</i> [...])	standard instruments for the difference equation only; can be specified more than once
liv(<i>varlist</i>)	standard instruments for the level equation only; can be specified more than once
<u>noconstant</u>	suppress constant term
<u>twostep</u>	compute the two-step estimator instead of the one-step estimator
<u>hascons</u>	check for collinearity only among levels of independent variables; by default checks occur among levels and differences
<u>fodeviation</u>	use forward-orthogonal deviations instead of first differences
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>gmm</u> or <u>robust</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>artests</u> (#)	use # as maximum order for AR tests; default is <u>artests</u> (2)
<i>display_options</i>	control spacing and line width
<u>coeflegend</u>	display legend instead of statistics

*dgmmiv() is required.
A panel variable and a time variable must be specified; use xtset; see [XT] xtset.
depvar, *indepvars*, and all *varlists* may contain time-series operators; see [U] 11.4.4 Time-series varlists.
by, *statsby*, and *xi* are allowed; see [U] 11.1.10 Prefix commands.
coeflegend does not appear in the dialog box.
See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Linear DPD estimation

Description

Linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. `xtdpd` fits a dynamic panel-data model by using the Arellano–Bond (1991) or the Arellano–Bover/Blundell–Bond (1995, 1998) estimator.

At the cost of a more complicated syntax, `xtdpd` can fit models with low-order moving-average correlation in the idiosyncratic errors or predetermined variables with a more complicated structure than allowed for `xtabond` or `xtdpdsys`; see [XT] [xtabond](#) and [XT] [xtdpdsys](#).

Options

Model

`dgmmlv(varlist [, lagrange(flag [llag]))` specifies GMM-type instruments for the differenced equation. Levels of the variables are used to form GMM-type instruments for the difference equation. All possible lags are used, unless `lagrange(flag llag)` restricts the lags to begin with *flag* and end with *llag*. You may specify as many sets of GMM-type instruments for the differenced equation as you need within the standard Stata limits on matrix size. Each set may have its own *flag* and *llag*. `dgmmlv()` is required.

`lgmmlv(varlist [, lag(#)])` specifies GMM-type instruments for the level equation. Differences of the variables are used to form GMM-type instruments for the level equation. The first lag of the differences is used unless `lag(#)` is specified, indicating that *#*th lag of the differences be used. You may specify as many sets of GMM-type instruments for the level equation as you need within the standard Stata limits on matrix size. Each set may have its own *lag*.

`iv(varlist [, nodifference])` specifies standard instruments for both the differenced and level equations. Differences of the variables are used as instruments for the differenced equations, unless `nodifference` is specified, which requests that levels be used. Levels of the variables are used as instruments for the level equations. You may specify as many sets of standard instruments for both the differenced and level equations as you need within the standard Stata limits on matrix size.

`div(varlist [, nodifference])` specifies additional standard instruments for the differenced equation. Specified variables may not be included in `iv()` or in `liv()`. Differences of the variables are used, unless `nodifference` is specified, which requests that levels of the variables be used as instruments for the differenced equation. You may specify as many additional sets of standard instruments for the differenced equation as you need within the standard Stata limits on matrix size.

`liv(varlist)` specifies additional standard instruments for the level equation. Specified variables may not be included in `iv()` or in `div()`. Levels of the variables are used as instruments for the level equation. You may specify as many additional sets of standard instruments for the level equation as you need within the standard Stata limits on matrix size.

`noconstant`; see [R] [estimation options](#).

`twostep` specifies that the two-step estimator be calculated.

hascons specifies that **xtdpd** check for collinearity only among levels of independent variables; by default checks occur among levels and differences.

fodeviation specifies that forward-orthogonal deviations are to be used instead of first differences. **fodeviation** is not allowed when there are gaps in the data or when **lgmiv()** is specified.

SE/Robust

vce(vcetype) specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see [Methods and formulas](#).

vce(gmm), the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

vce(robust) uses the robust estimator. For the one-step estimator, this is the Arellano–Bond robust VCE estimator. For the two-step estimator, this is the [Windmeijer \(2005\)](#) WC-robust estimator.

Reporting

level(#); see [\[R\] estimation options](#).

artests(#) specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by **estat abond**; see [\[XT\] xtdpd postestimation](#). Specifying the order of the highest test at estimation time is more efficient than specifying it to **estat abond**, because **estat abond** must refit the model to obtain the test statistics. The maximum order must be less than or equal to the number of periods in the longest panel. The default is **artests(2)**.

display_options: **vsquish** and **nolstretch**; see [\[R\] estimation options](#).

The following option is available with **xtdpd** but is not shown in the dialog box:

coeflegend; see [\[R\] estimation options](#).

Remarks and examples

If you have not read [\[XT\] xtabond](#) and [\[XT\] xtdpdsys](#), you should do so before continuing.

Consider the dynamic panel-data model

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it} \boldsymbol{\beta}_1 + \mathbf{w}_{it} \boldsymbol{\beta}_2 + \nu_i + \epsilon_{it} \quad i = \{1, \dots, N\}; \quad t = \{1, \dots, T_i\} \quad (1)$$

where

the $\alpha_1, \dots, \alpha_p$ are p parameters to be estimated,

\mathbf{x}_{it} is a $1 \times k_1$ vector of strictly exogenous covariates,

$\boldsymbol{\beta}_1$ is a $k_1 \times 1$ vector of parameters to be estimated,

\mathbf{w}_{it} is a $1 \times k_2$ vector of predetermined covariates,

$\boldsymbol{\beta}_2$ is a $k_2 \times 1$ vector of parameters to be estimated,

ν_i are the panel-level effects (which may be correlated with x_{it} or w_{it}), and

and ϵ_{it} are i.i.d. or come from a low-order moving-average process, with variance σ_ϵ^2 .

Building on the work of Anderson and Hsiao (1981, 1982) and Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991) derived one-step and two-step GMM estimators using moment conditions in which lagged levels of the dependent and predetermined variables were instruments for the differenced equation. Blundell and Bond (1998) show that the lagged-level instruments in the Arellano–Bond estimator become weak as the autoregressive process becomes too persistent or the ratio of the variance of the panel-level effect ν_i to the variance of the idiosyncratic error ϵ_{it} becomes too large. Building on the work of Arellano and Bover (1995), Blundell and Bond (1998) proposed a system estimator that uses moment conditions in which lagged differences are used as instruments for the level equation in addition to the moment conditions of lagged levels as instruments for the differenced equation. The additional moment conditions are valid only if the initial condition $E[\nu_i \Delta y_{i2}] = 0$ holds for all i ; see Blundell and Bond (1998) and Blundell, Bond, and Windmeijer (2000).

`xtdpd` fits dynamic panel-data models by using the Arellano–Bond or the Arellano–Bover/Blundell–Bond system estimator. The parameters of many standard models can be more easily estimated using the Arellano–Bond estimator implemented in `xtabond` or using the Arellano–Bover/Blundell–Bond system estimator implemented in `xtdpdsys`; see [XT] `xtabond` and [XT] `xtdpdsys`. `xtdpd` can fit more complex models at the cost of a more complicated syntax. That the idiosyncratic errors follow a low-order MA process and that the predetermined variables have a more complicated structure than accommodated by `xtabond` and `xtdpdsys` are two common reasons for using `xtdpd` instead of `xtabond` or `xtdpdsys`.

The standard GMM robust two-step estimator of the VCE is known to be seriously biased. Windmeijer (2005) derived a bias-corrected robust estimator for two-step VCEs from GMM estimators known as the WC-robust estimator, which is implemented in `xtdpd`.

The Arellano–Bond test of autocorrelation of order m and the Sargan test of overidentifying restrictions derived by Arellano and Bond (1991) are computed by `xtdpd` but reported by `estat abond` and `estat sargan`, respectively; see [XT] `xtdpd postestimation`.

Because `xtdpd` extends `xtabond` and `xtdpdsys`, [XT] `xtabond` and [XT] `xtdpdsys` provide useful background.

▶ Example 1: An Arellano–Bond estimator

Arellano and Bond (1991) apply their new estimators and test statistics to a model of dynamic labor demand that had previously been considered by Layard and Nickell (1986), using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm i and time t . In this dataset, `nit` is the log of employment in firm i inside the United Kingdom at time t , `wit` is the natural log of the real product wage, `kit` is the natural log of the gross capital stock, and `ysit` is the natural log of industry output. The model also includes time dummies `yr1980`, `yr1981`, `yr1982`, `yr1983`, and `yr1984`. To gain some insight into the syntax for `xtdpd`, we reproduce the first example from [XT] `xtabond` using `xtdpd`:


```
. use http://www.stata-press.com/data/r13/abdata
. xtdpd L(0/2).n L(0/1).w L(0/2).(k ys) yr1980-yr1984 year, noconstant
> div(L(0/1).w L(0/2).(k ys) yr1980-yr1984 year) dgmiv(n)

Dynamic panel-data estimation      Number of obs      =      611
Group variable: id                Number of groups   =      140
Time variable: year

                                Obs per group:   min =      4
                                                avg =  4.364286
                                                max =      6

Number of instruments =      41      Wald chi2(16)      =  1757.07
                                      Prob > chi2        =   0.0000
```

One-step results

n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6862261	.1486163	4.62	0.000	.3949435	.9775088
L2.	-.0853582	.0444365	-1.92	0.055	-.1724523	.0017358
w						
--.	-.6078208	.0657694	-9.24	0.000	-.7367265	-.4789151
L1.	.3926237	.1092374	3.59	0.000	.1785222	.6067251
k						
--.	.3568456	.0370314	9.64	0.000	.2842653	.4294259
L1.	-.0580012	.0583051	-0.99	0.320	-.172277	.0562747
L2.	-.0199475	.0416274	-0.48	0.632	-.1015357	.0616408
ys						
--.	.6085073	.1345412	4.52	0.000	.3448115	.8722031
L1.	-.7111651	.1844599	-3.86	0.000	-1.0727	-.3496304
L2.	.1057969	.1428568	0.74	0.459	-.1741974	.3857912
yr1980	.0029062	.0212705	0.14	0.891	-.0387832	.0445957
yr1981	-.0404378	.0354707	-1.14	0.254	-.1099591	.0290836
yr1982	-.0652767	.048209	-1.35	0.176	-.1597646	.0292111
yr1983	-.0690928	.0627354	-1.10	0.271	-.1920521	.0538664
yr1984	-.0650302	.0781322	-0.83	0.405	-.2181665	.0881061
year	.0095545	.0142073	0.67	0.501	-.0182912	.0374002

Instruments for differenced equation

```
GMM-type: L(2/).n
Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980
          D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year
```

Unlike most instrumental-variables estimation commands, the independent variables in the varlist are not automatically used as instruments. In this example, all the independent variables are strictly exogenous, so we include them in `div()`, a list of variables whose first differences will be instruments for the differenced equation. We include the dependent variable in `dgmiv()`, a list of variables whose lagged levels will be used to create GMM-type instruments for the differenced equation. (GMM-type instruments are discussed in a [technical note](#) below.)

The footer in the output reports the instruments used. The first line indicates that `xtdpd` used lags from 2 on back to create the GMM-type instruments described in [Arellano and Bond \(1991\)](#) and [Holtz-Eakin, Newey, and Rosen \(1988\)](#). The second line says that the first difference of all the variables included in the `div()` varlist were used as standard instruments for the differenced equation.

□ Technical note

GMM-type instruments are built from lags of one variable. Ignoring the strictly exogenous variables for simplicity, our model is

$$n_{it} = \alpha_1 n_{it-1} + \alpha_2 n_{it-2} + \nu_i + \epsilon_{it} \quad (2)$$

After differencing we have

$$\Delta n_{it} = \Delta \alpha_1 n_{it-1} + \Delta \alpha_2 n_{it-2} + \Delta \epsilon_{it} \quad (3)$$

Equation (3) implies that we need instruments that are not correlated with either ϵ_{it} or ϵ_{it-1} . Equation (2) shows that L2.n is the first lag of n that is not correlated with ϵ_{it} or ϵ_{it-1} , so it is the first lag of n that can be used to instrument the differenced equation.

Consider the following data from one of the complete panels in the [previous example](#):

```
. list id year n L2.n dL2.n if id==140
```

	id	year	n	L2. n	L2D. n
1023.	140	1976	.4324315	.	.
1024.	140	1977	.3694925	.	.
1025.	140	1978	.3541718	.4324315	.
1026.	140	1979	.3632532	.3694925	-.0629391
1027.	140	1980	.3371863	.3541718	-.0153207
1028.	140	1981	.285179	.3632532	.0090815
1029.	140	1982	.1756326	.3371863	-.026067
1030.	140	1983	.1275133	.285179	-.0520073
1031.	140	1984	.0889263	.1756326	-.1095464

The missing values in L2D.n show that we lose 3 observations because of lags and the difference that removes the panel-level effects. The first nonmissing observation occurs in 1979 and observations on n from 1976 and 1977 are available to instrument the 1979 differenced equation. The table below gives the observations available to instrument the differenced equation for the data above.

Year of difference errors	Years of instruments	Number of instruments
1979	1976–1977	2
1980	1976–1978	3
1981	1976–1979	4
1982	1976–1980	5
1983	1976–1981	6
1984	1976–1982	7

The table shows that there are a total of 27 GMM-type instruments.

The output in the example above informs us that there were a total of 41 instruments applied to the differenced equation. Because there are 14 standard instruments, there must have been 27 GMM-type instruments, which matches our above calculation.

□

▶ Example 2: An Arellano–Bond estimator with predetermined variables

Sometimes we cannot assume strict exogeneity. Recall that a variable x_{it} is said to be strictly exogenous if $E[x_{it}\epsilon_{is}] = 0$ for all t and s . If $E[x_{it}\epsilon_{is}] \neq 0$ for $s < t$ but $E[x_{it}\epsilon_{is}] = 0$ for all $s \geq t$, the variable is said to be predetermined. Intuitively, if the error term at time t has some feedback on the subsequent realizations of x_{it} , x_{it} is a predetermined variable. In the output below, we use `xtdpd` to reproduce [example 6](#) in [\[XT\] xtabond](#).

```

. xtdpd L(0/2).n L(0/1).(w ys) L(0/2).k yr1980-yr1984 year,
> div(L(0/1).(ys) yr1980-yr1984 year) dgmmliv(n) dgmmliv(L.w L2.k, lag(1.))
> twostep noconstant vce(robust)

Dynamic panel-data estimation      Number of obs      =      611
Group variable: id                Number of groups   =      140
Time variable: year

                                Obs per group:   min =       4
                                                avg =   4.364286
                                                max =       6

Number of instruments =      83      Wald chi2(15)      =   958.30
                                      Prob > chi2      =   0.0000

Two-step results
                                (Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.8580958	.1265515	6.78	0.000	.6100594	1.106132
L2.	-.081207	.0760703	-1.07	0.286	-.2303022	.0678881
w						
--.	-.6910855	.1387684	-4.98	0.000	-.9630666	-.4191044
L1.	.5961712	.1497338	3.98	0.000	.3026982	.8896441
ys						
--.	.6936392	.1728623	4.01	0.000	.3548354	1.032443
L1.	-.8773678	.2183085	-4.02	0.000	-1.305245	-.449491
k						
--.	.4140654	.1382788	2.99	0.003	.1430439	.6850868
L1.	-.1537048	.1220244	-1.26	0.208	-.3928681	.0854586
L2.	-.1025833	.0710886	-1.44	0.149	-.2419143	.0367477
yr1980	-.0072451	.017163	-0.42	0.673	-.0408839	.0263938
yr1981	-.0609608	.030207	-2.02	0.044	-.1201655	-.0017561
yr1982	-.1130369	.0454826	-2.49	0.013	-.2021812	-.0238926
yr1983	-.1335249	.0600213	-2.22	0.026	-.2511645	-.0158853
yr1984	-.1623177	.0725434	-2.24	0.025	-.3045001	-.0201352
year	.0264501	.0119329	2.22	0.027	.003062	.0498381

```

Instruments for differenced equation
GMM-type: L(2/.)n L(1/.)L.w L(1/.)L2.k
Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984
          D.year
```

The footer informs us that we are now including GMM-type instruments from the first lag of `L.w` on back and from the first lag of `L2.k` on back.

Example 3: A weaker definition of predetermined variables

As discussed in [XT] [xtabond](#) and [XT] [xtdpdsys](#), [xtabond](#) and [xtdpdsys](#) both use a strict definition of predetermined variables with lags. In the strict definition, the most recent lag of the variable in `pre()` is considered predetermined. (Here specifying `pre(w, lag(1, .))` to [xtabond](#) means that `L.w` is a predetermined variable and `pre(k, lag(2, .))` means that `L2.k` is a predetermined variable.) In a weaker definition, the current observation is considered predetermined, but subsequent lags are included in the model. Here `w` and `k` would be predetermined instead of `L.w` and `L2.w`. The output below implements this weaker definition for the [previous example](#).

```
. xtdpd L(0/2).n L(0/1).(w ys) L(0/2).k yr1980-yr1984 year,
> div(L(0/1).(ys) yr1980-yr1984 year) dgmminv(n) dgmminv(w k, lag(1 .))
> twostep noconstant vce(robust)
```

Dynamic panel-data estimation

Group variable: id

Time variable: year

Number of obs = 611

Number of groups = 140

Obs per group: min = 4

avg = 4.364286

max = 6

Number of instruments = 101

Wald chi2(15) = 879.53

Prob > chi2 = 0.0000

Two-step results

(Std. Err. adjusted for clustering on id)

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.6343155	.1221058	5.19	0.000	.3949925 .8736384
L2.	-.0871247	.0704816	-1.24	0.216	-.2252661 .0510168
w					
--.	-.720063	.1133359	-6.35	0.000	-.9421973 -.4979287
L1.	.238069	.1223186	1.95	0.052	-.0016712 .4778091
ys					
--.	.5999718	.1653036	3.63	0.000	.2759827 .923961
L1.	-.5674808	.1656411	-3.43	0.001	-.8921314 -.2428303
k					
--.	.3931997	.0986673	3.99	0.000	.1998153 .5865842
L1.	-.0019641	.0772814	-0.03	0.980	-.1534329 .1495047
L2.	-.0231165	.0487317	-0.47	0.635	-.1186288 .0723958
yr1980	-.006209	.0162138	-0.38	0.702	-.0379875 .0255694
yr1981	-.0398491	.0313794	-1.27	0.204	-.1013516 .0216535
yr1982	-.0525715	.0397346	-1.32	0.186	-.1304498 .0253068
yr1983	-.0451175	.051418	-0.88	0.380	-.145895 .05566
yr1984	-.0437772	.0614391	-0.71	0.476	-.1641955 .0766412
year	.0173374	.0108665	1.60	0.111	-.0039605 .0386352

Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).w L(1/.).k

Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984

D.year

As expected, the output shows that the additional 18 instruments available under the weaker definition can affect the magnitudes of the estimates. Applying the stricter definition when the true model was generated by the weaker definition yielded consistent but inefficient results; there were some additional

moment conditions that could have been included but were not. In contrast, applying the weaker definition when the true model was generated by the stricter definition yields inconsistent estimates.

► **Example 4: A system estimator of a dynamic panel-data model**

Here we use `xtdpd` to reproduce [example 2](#) from [\[XT\] xtdpdsys](#) in which we used the system estimator to fit a model with predetermined variables.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(yr1980-yr1984 year) dgmdiv(n) dgmdiv(L2.(w k), lag(1 .))
> lgmmiv(n L1.(w k)) vce(robust) hascons

Dynamic panel-data estimation                Number of obs      =       751
Group variable: id                          Number of groups    =       140
Time variable: year

Obs per group:   min =          5
                  avg =   5.364286
                  max =          7

Number of instruments =      95              Wald chi2(13)       =    7562.80
                                                Prob > chi2        =     0.0000

One-step results
                                         (Std. Err. adjusted for clustering on id)

+-----+-----+-----+-----+-----+-----+
|      n      |      Coef.      | Robust Std. Err. |      z      | P>|z| | [95% Conf. Interval] |
+-----+-----+-----+-----+-----+-----+
|      n      |      .913278    |   .0460602      |   19.83    | 0.000 |   .8230017   1.003554 |
|      L1.    |      .5602737   |   .1939617      |    2.89    | 0.004 |   .1801156   .9404317 |
|      L2.    |   -.0523028    |   .1487653      |   -0.35    | 0.725 |  -.3438775   .2392718 |
|      w      |      --.        |      --.         |      --.   |      |      --.      --.      |
|      L1.    |   -.728159     |   .1019044      |   -7.15    | 0.000 |  -.927888   -.5284301 |
|      L2.    |   .5602737     |   .1939617      |    2.89    | 0.004 |   .1801156   .9404317 |
|      k      |      --.        |      --.         |      --.   |      |      --.      --.      |
|      L1.    |   -.2846944    |   .0831902      |   -3.42    | 0.001 |  -.4477442   -.1216446 |
|      L2.    |   -.1394181    |   .0405709      |   -3.44    | 0.001 |  -.2189356   -.0599006 |
| yr1980     |   -.0325146    |   .0216371      |   -1.50    | 0.133 |  -.0749226   .0098935 |
| yr1981     |   -.0726116    |   .0346482      |   -2.10    | 0.036 |  -.1405207   -.0047024 |
| yr1982     |   -.0477038    |   .0451914      |   -1.06    | 0.291 |  -.1362772   .0408696 |
| yr1983     |   -.0396264    |   .0558734      |   -0.71    | 0.478 |  -.1491362   .0698835 |
| yr1984     |   -.0810383    |   .0736648      |   -1.10    | 0.271 |  -.2254186   .063342 |
| year       |   .0192741     |   .0145326      |    1.33    | 0.185 |  -.0092092   .0477574 |
| _cons      |  -37.34972     |   28.77747      |   -1.30    | 0.194 |  -93.75253   19.05308 |
+-----+-----+-----+-----+-----+-----+

Instruments for differenced equation
GMM-type: L(2/.)n L(1/.)L2.w L(1/.)L2.k
Standard: D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.yr1985
Instruments for level equation
GMM-type: LD.n L2D.w L2D.k
Standard: _cons
```

The first lags of the variables included in `lgmmiv()` are used to create GMM-type instruments for the level equation. Only the first lags of the variables in `lgmmiv()` are used because the moment conditions using higher lags are redundant; see [Blundell and Bond \(1998\)](#) and [Blundell, Bond, and Windmeijer \(2000\)](#).

Example 5: Allowing for MA(1) errors

All the previous examples have used moment conditions that are valid only if the idiosyncratic errors are i.i.d. This example shows how to use xtdpd to estimate the parameters of a model with first-order moving-average [MA(1)] errors using the Arellano–Bond estimator, the Arellano–Bover/Blundell–Bond system estimator, or any other consistent GMM estimator you want to specify. For simplicity, we assume that the independent variables are strictly exogenous. Also, to highlight the fact that we can specify the instrument list flexibly, we only include the levels and first lags of the exogenous variables in the instrument list. An Arellano–Bond estimator, for instance, would have included levels and first and second lags of the exogenous variables.

We begin by noting that the Sargan test rejects the null hypothesis that the overidentifying restrictions are valid in the model with i.i.d. errors.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmiv(n) hascons
(output omitted)
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(24)      = 49.70094
Prob > chi2   = 0.0015
```

Assuming that the idiosyncratic errors are MA(1) implies that only lags three or higher are valid instruments for the differenced equation. (See the [technical note](#) below.)

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmiv(n, lag(3 .)) hascons
Dynamic panel-data estimation      Number of obs      =      751
Group variable: id                Number of groups   =      140
Time variable: year

Obs per group:    min =      5
                  avg = 5.364286
                  max =      7

Number of instruments =      32      Wald chi2(13)      = 1195.04
                                      Prob > chi2        = 0.0000
```

One-step results

	n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n							
L1.		.8696303	.2014473	4.32	0.000	.4748008	1.26446
w							
--.		-.5802971	.0762659	-7.61	0.000	-.7297756	-.4308187
L1.		.2918658	.1543883	1.89	0.059	-.0107296	.5944613
L2.		-.5903459	.2995123	-1.97	0.049	-1.177379	-.0033126
k							
--.		.3428139	.0447916	7.65	0.000	.2550239	.4306039
L1.		-.1383918	.0825823	-1.68	0.094	-.3002502	.0234665
L2.		-.0260956	.1535855	-0.17	0.865	-.3271177	.2749265
yr1980		-.0036873	.0301587	-0.12	0.903	-.0627973	.0554226
yr1981		.00218	.0592014	0.04	0.971	-.1138526	.1182125
yr1982		.0782939	.0897622	0.87	0.383	-.0976367	.2542246
yr1983		.1734231	.1308914	1.32	0.185	-.0831193	.4299655
yr1984		.2400685	.1734456	1.38	0.166	-.0998787	.5800157
year		-.0354681	.0309963	-1.14	0.253	-.0962198	.0252836
_cons		73.13706	62.61443	1.17	0.243	-49.58496	195.8591


```
Instruments for differenced equation
      GMM-type: L(3/.)n
      Standard: D.w LD.w D.k LD.k D.yr1980 D.yr1981 D.yr1982 D.yr1983
               D.yr1984 D.year
Instruments for level equation
      Standard: _cons
```

The results from `estat sargan` no longer reject the null hypothesis that the overidentifying restrictions are valid.

```
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
      chi2(18)      = 20.80081
      Prob > chi2   = 0.2896
```

Moving on to the system estimator, we note that the Sargan test rejects the null hypothesis after fitting the model with i.i.d. errors.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmiv(n) lgmmiv(n) hascons
(output omitted)
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
      chi2(31)      = 59.22907
      Prob > chi2   = 0.0017
```

Now we fit the model using the additional moment conditions constructed from the second lag of `n` as an instrument for the level equation.


```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmiv(n, lag(3 .)) lgmmiv(n, lag(2))
> hascons
```

Dynamic panel-data estimation	Number of obs	=	751
Group variable: id	Number of groups	=	140
Time variable: year	Obs per group:	min =	5
		avg =	5.364286
		max =	7
Number of instruments =	38	Wald chi2(13)	= 3680.01
		Prob > chi2	= 0.0000

One-step results

n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.9603675	.095608	10.04	0.000	.7729794	1.147756
w						
--.	-.5433987	.068835	-7.89	0.000	-.6783128	-.4084845
L1.	.4356183	.0881727	4.94	0.000	.262803	.6084336
L2.	-.2785721	.1115061	-2.50	0.012	-.4971201	-.0600241
k						
--.	.3139331	.0419054	7.49	0.000	.2317999	.3960662
L1.	-.160103	.0546915	-2.93	0.003	-.2672963	-.0529096
L2.	-.1295766	.0507752	-2.55	0.011	-.2290943	-.030059
yr1980	-.0200704	.0248954	-0.81	0.420	-.0688644	.0287236
yr1981	-.0425838	.0422155	-1.01	0.313	-.1253246	.040157
yr1982	.0048723	.0600938	0.08	0.935	-.1129093	.122654
yr1983	.0458978	.0785687	0.58	0.559	-.1080941	.1998897
yr1984	.0633219	.1026188	0.62	0.537	-.1378074	.2644511
year	-.0075599	.019059	-0.40	0.692	-.0449148	.029795
_cons	16.20856	38.00619	0.43	0.670	-58.28221	90.69932

```
Instruments for differenced equation
GMM-type: L(3/.)n
Standard: D.w LD.w D.k LD.k D.yr1980 D.yr1981 D.yr1982 D.yr1983
D.yr1984 D.year
Instruments for level equation
GMM-type: L2D.n
Standard: _cons
```

The estimate of the coefficient on L.n is now .96. [Blundell, Bond, and Windmeijer \(2000, 63–65\)](#) show that the moment conditions in the system estimator remain informative as the true coefficient on L.n approaches unity. [Holtz-Eakin, Newey, and Rosen \(1988\)](#) show that because the large-sample distribution of the estimator is derived for fixed number of periods and a growing number of individuals there is no “unit-root” problem.

The results from `estat sargan` no longer reject the null hypothesis that the overidentifying restrictions are valid.

```
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(24) = 27.22585
Prob > chi2 = 0.2940
```


□ Technical note

To find the valid moment conditions for the model with MA(1) errors, we begin by writing the model

$$n_{it} = \alpha n_{it-1} + \beta x_{it} + \nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$$

where the ϵ_{it} are assumed to be i.i.d.

Because the composite error, $\epsilon_{it} + \gamma \epsilon_{it-1}$, is MA(1), only lags two or higher are valid instruments for the level equation, assuming the initial condition that $E[\nu_i \Delta n_{i2}] = 0$. The key to this point is that lagging the above equation two periods shows that ϵ_{it-2} and ϵ_{it-3} appear in the equation for n_{it-2} . Because the ϵ_{it} are i.i.d., n_{it-2} is a valid instrument for the level equation with errors $\nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$. (n_{it-2} will be correlated with n_{it-1} but uncorrelated with the errors $\nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$.) An analogous argument works for higher lags.

First-differencing the above equation yields

$$\Delta n_{it} = \alpha \Delta n_{it-1} + \beta \Delta x_{it} + \Delta \epsilon_{it} + \gamma \Delta \epsilon_{it-1}$$

Because ϵ_{it-2} is the farthest lag of ϵ_{it} that appears in the differenced equation, lags three or higher are valid instruments for the differenced composite errors. (Lagging the level equation three periods shows that only ϵ_{it-3} and ϵ_{it-4} appear in the equation for n_{it-3} , which implies that n_{it-3} is a valid instrument for the current differenced equation. An analogous argument works for higher lags.)

□

Stored results

`xtdpd` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	χ^2
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of σ_ϵ^2
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

Macros

e(cmd)	xtddpd
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(twostep)	twostep, if specified
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(vce)	vcetype specified in vce()
e(vcetype)	title used to label Std. Err.
e(system)	system, if system estimator
e(hascons)	hascons, if specified
e(transform)	specified transform
e(datasignature)	checksum from datasignature
e(properties)	b V
e(estat_cmd)	program used to implement estat
e(predict)	program used to implement predict
e(marginsok)	predictions allowed by margins

Matrices

e(b)	coefficient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
-----------	-------------------------

Methods and formulas

Consider dynamic panel-data models of the form

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it} \beta_1 + \mathbf{w}_{it} \beta_2 + \nu_i + \epsilon_{it}$$

where the variables are as defined as in (1).

\mathbf{x} and \mathbf{w} may contain lagged independent variables and time dummies.

Let $\mathbf{X}_{it}^L = (y_{i,t-1}, y_{i,t-2}, \dots, y_{i,t-p}, \mathbf{x}_{it}, \mathbf{w}_{it})$ be the $1 \times K$ vector of covariates for i at time t , where $K = p + k_1 + k_2$, p is the number of included lags, k_1 is the number of strictly exogenous variables in x_{it} , and k_2 is the number of predetermined variables in w_{it} . (The superscript L stands for levels.)

Now rewrite this relationship as a set of T_i equations for each individual,

$$\mathbf{y}_i^L = \mathbf{X}_i^L \boldsymbol{\delta} + \nu_i \mathbf{1}_i + \boldsymbol{\epsilon}_i$$

where T_i is the number of observations available for individual i ; \mathbf{y}_i , $\mathbf{1}_i$, and $\boldsymbol{\epsilon}_i$ are $T_i \times 1$, whereas \mathbf{X}_i is $T_i \times K$.

The estimators use both the levels and a transform of the variables in the above equation. Denote the transformed variables by an $*$, so that \mathbf{y}_i^* is the transformed \mathbf{y}_i^L and \mathbf{X}_i^* is the transformed \mathbf{X}_i^L . The transform may be either the first difference or the forward-orthogonal deviations (FOD) transform. The (i, t) th observation of the FOD transform of a variable \mathbf{x} is given by

$$x_{it}^* = c_t \left\{ x_{it} - \frac{1}{T-t} (x_{it+1} + x_{it+2} + \dots + x_{iT}) \right\}$$

where $c_t^2 = (T-t)/(T-t+1)$ and T is the number of observations on \mathbf{x} ; see [Arellano and Bover \(1995\)](#) and [Arellano \(2003\)](#).

Here we present the formulas for the Arellano–Bover/Blundell–Bond system estimator. The formulas for the Arellano–Bond estimator are obtained by setting the additional level matrices in the system estimator to null matrices.

Stacking the transformed and untransformed vectors of the dependent variable for a given i yields

$$\mathbf{y}_i = \begin{pmatrix} \mathbf{y}_i^* \\ \mathbf{y}_i^L \end{pmatrix}$$

Similarly, stacking the transformed and untransformed matrices of the covariates for a given i yields

$$\mathbf{X}_i = \begin{pmatrix} \mathbf{X}_i^* \\ \mathbf{X}_i^L \end{pmatrix}$$

\mathbf{Z}_i is a matrix of instruments,

$$\mathbf{Z}_i = \begin{pmatrix} \mathbf{Z}_{di} & \mathbf{0} & \mathbf{D}_i & \mathbf{0} & \mathbf{I}_i^d \\ \mathbf{0} & \mathbf{Z}_{Li} & \mathbf{0} & \mathbf{L}_i & \mathbf{I}_i^L \end{pmatrix}$$

where \mathbf{Z}_{di} is the matrix of GMM-type instruments created from the `dgmiv()` options, \mathbf{Z}_{Li} is the matrix of GMM-type instruments created from the `lgmiv()` options, \mathbf{D}_i is the matrix of standard instruments created from the `div()` options, \mathbf{L}_i is the matrix of standard instruments created from the `liv()` options, \mathbf{I}_i^d is the matrix of standard instruments created from the `iv()` options for the differenced errors, and \mathbf{I}_i^L is the matrix of standard instruments created from the `iv()` options for the level errors.

`div()`, `liv()`, and `iv()` simply add columns to instrument matrix. The GMM-type instruments are more involved. Begin by considering a simple balanced-panel example in which our model is

$$y_{it} = \alpha_1 y_{i,t-1} + \alpha_2 y_{i,t-2} + \nu_i + \epsilon_{it}$$

We do not need to consider covariates because strictly exogenous variables are handled using `div()`, `iv()`, or `liv()`, and predetermined or endogenous variables are handled analogous to the dependent variable.

Assume that the data come from a balanced panel in which there are no missing values. After first-differencing the equation, we have

$$\Delta y_{it} = \alpha_1 \Delta y_{i,t-1} + \alpha_2 \Delta y_{i,t-2} + \Delta \epsilon_{it}$$

The first 3 observations are lost to lags and differencing. If we assume that the ϵ_{it} are not autocorrelated, for each i at $t = 4$, y_{i1} and y_{i2} are valid instruments for the differenced equation. Similarly, at $t = 5$, y_{i1} , y_{i2} , and y_{i3} are valid instruments. We specify `dgmiv(y)` to obtain an instrument matrix with one row for each period that we are instrumenting:

$$\mathbf{Z}_{di} = \begin{pmatrix} y_{i1} & y_{i2} & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & y_{i1} & y_{i2} & y_{i3} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & 0 & y_{i1} & \dots & y_{i,T-2} \end{pmatrix}$$

Because $p = 2$, \mathbf{Z}_{di} has $T - p - 1$ rows and $\sum_{m=p}^{T-2} m$ columns.

Specifying `lgmmiv(y)` creates the instrument matrix

$$\mathbf{Z}_{Li} = \begin{pmatrix} \Delta.y_{i2} & 0 & 0 & \dots & 0 \\ 0 & \Delta.y_{i3} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \Delta.y_{i(T_i-1)} \end{pmatrix}$$

This extends to other lag structures with complete data. Unbalanced data and missing observations are handled by dropping the rows for which there are no data and filling in zeros in columns where missing data are required. Suppose that, for some i , the $t = 1$ observation was missing but was not missing for some other panels. `dgmmiv(y)` would then create the instrument matrix

$$\mathbf{Z}_{di} = \begin{pmatrix} 0 & 0 & 0 & y_{i2} & y_{i3} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & y_{i2} & y_{i3} & 0 & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & y_{i2} & \dots & y_{iT-2} \end{pmatrix}$$

\mathbf{Z}_{di} has $T_i - p - 1$ rows and $\sum_{m=p}^{\tau-2} m$ columns, where $\tau = \max_i \tau_i$ and τ_i is the number of nonmissing observations in panel i .

After defining

$$\mathbf{Q}_{xz} = \sum_i \mathbf{X}'_i \mathbf{Z}_i$$

$$\mathbf{Q}_{zy} = \sum_i \mathbf{Z}'_i \mathbf{y}_i$$

$$\mathbf{W}_1 = \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}'_{xz}$$

$$\mathbf{A}_1 = \left(\sum_i \mathbf{Z}'_i \mathbf{H}_{1i} \mathbf{Z}_i \right)^{-1}$$

and

$$\mathbf{H}_{1i} = \begin{pmatrix} \mathbf{H}_{di} & \mathbf{0} \\ \mathbf{0} & \mathbf{H}_{Li} \end{pmatrix}$$

the one-step estimates are given by

$$\hat{\beta}_1 = \mathbf{W}_1^{-1} \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}_{zy}$$

When using the first-difference transform \mathbf{H}_{di} , is given by

$$\mathbf{H}_{di} = \begin{pmatrix} 1 & -.5 & 0 & \dots & 0 & 0 \\ -.5 & 1 & -.5 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 & -.5 \\ 0 & 0 & 0 & \dots & -.5 & 1 \end{pmatrix}$$

and \mathbf{H}_{Li} is given by 0.5 times the identity matrix. When using the FOD transform, both \mathbf{H}_{di} and \mathbf{H}_{Li} are equal to the identity matrix.

The transformed one-step residuals are given by

$$\hat{\epsilon}_{1i}^* = \mathbf{y}_i^* - \hat{\beta}_1 \mathbf{X}_i^*$$

which are used to compute

$$\hat{\sigma}_1^2 = (1/(N - K)) \sum_i^N \hat{\epsilon}_{1i}^{*'} \hat{\epsilon}_{1i}^*$$

The GMM one-step VCE is then given by

$$\hat{V}_{\text{GMM}}[\hat{\beta}_1] = \hat{\sigma}_1^2 \mathbf{W}_1^{-1}$$

The one-step level residuals are given by

$$\hat{\epsilon}_{1i}^L = \mathbf{y}_i^L - \hat{\beta}_1 \mathbf{X}_i^L$$

Stacking the residual vectors yields

$$\hat{\epsilon}_{1i} = \begin{pmatrix} \hat{\epsilon}_{1i}^* \\ \hat{\epsilon}_{1i}^L \end{pmatrix}$$

which is used to compute $\mathbf{H}_{2i} = \hat{\epsilon}_{1i}' \hat{\epsilon}_{1i}$, which is used in

$$\mathbf{A}_2 = \left(\sum_i \mathbf{Z}_i' \mathbf{H}_{2i} \mathbf{Z}_i \right)^{-1}$$

and the robust one-step VCE is given by

$$\hat{V}_{\text{robust}}[\hat{\beta}_1] = \mathbf{W}_1^{-1} \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{A}_2^{-1} \mathbf{A}_1 \mathbf{Q}_{xz}' \mathbf{W}_1^{-1}$$

$\hat{V}_{\text{robust}}[\hat{\beta}_1]$ is robust to heteroskedasticity in the errors.

After defining

$$\mathbf{W}_2 = \mathbf{Q}_{xz} \mathbf{A}_2 \mathbf{Q}_{xz}'$$

the two-step estimates are given by

$$\hat{\beta}_2 = \mathbf{W}_2^{-1} \mathbf{Q}_{xz} \mathbf{A}_2 \mathbf{Q}_{zy}$$

The GMM two-step VCE is then given by

$$\hat{V}_{\text{GMM}}[\hat{\beta}_2] = \mathbf{W}_2^{-1}$$

The GMM two-step VCE is known to be severely biased. Windmeijer (2005) derived the Windmeijer bias-corrected (WC) estimator for the robust VCE of two-step GMM estimators. `xtdpd` implements this WC-robust estimator of the VCE. The formulas for this method are involved; see Windmeijer (2005). The WC-robust estimator of the VCE is robust to heteroskedasticity in the errors.

Acknowledgment

We thank David Roodman of the Center for Global Development, who wrote `xtabond2`.

References

- Anderson, T. W., and C. Hsiao. 1981. Estimation of dynamic models with error components. *Journal of the American Statistical Association* 76: 598–606.
- . 1982. Formulation and estimation of dynamic models using panel data. *Journal of Econometrics* 18: 47–82.
- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.
- Arellano, M., and O. Bover. 1995. Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics* 68: 29–51.
- Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Blackburne, E. F., III, and M. W. Frank. 2007. Estimation of nonstationary heterogeneous panels. *Stata Journal* 7: 197–208.
- Blundell, R., and S. Bond. 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87: 115–143.
- Blundell, R., S. Bond, and F. Windmeijer. 2000. Estimation in dynamic panel data models: Improving on the performance of the standard GMM estimator. In *Nonstationary Panels, Cointegrating Panels and Dynamic Panels*, ed. B. H. Baltagi, 53–92. New York: Elsevier.
- Bruno, G. S. F. 2005. Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *Stata Journal* 5: 473–500.
- Hansen, L. P. 1982. Large sample properties of generalized method of moments estimators. *Econometrica* 50: 1029–1054.
- Holtz-Eakin, D., W. K. Newey, and H. S. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* 56: 1371–1395.
- Layard, R., and S. J. Nickell. 1986. Unemployment in Britain. *Economica* 53: S121–S169.
- Windmeijer, F. 2005. A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics* 126: 25–51.

Also see

[XT] **xtdpd postestimation** — Postestimation tools for xtdpd

[XT] **xtset** — Declare data to be panel data

[XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation

[XT] **xtdpdsys** — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation

[XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models

[XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models

[XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance

[R] **gmm** — Generalized method of moments estimation

[U] **20 Estimation and postestimation commands**

Description	Syntax for predict	Menu for predict
Options for predict	Syntax for estat	Menu for estat
Option for estat abond	Remarks and examples	Methods and formulas
Reference	Also see	

Description

The following postestimation commands are of special interest after `xtdpd`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Special-interest postestimation commands

- `estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced residuals.
- `estat sargan` reports the Sargan test of the overidentifying restrictions.

Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

e calculates the residual error.

stdp calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. **stdp** may not be combined with **difference**.

difference specifies that the statistic be calculated for the first differences instead of the levels, the default.

Syntax for estat

Test for autocorrelation

```
estat abond [, artests(#)]
```

Sargan test of overidentifying restrictions

```
estat sargan
```

Menu for estat

Statistics > Postestimation > Reports and statistics

Option for estat abond

artests(#) specifies highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when **artests(#)** specifies a higher order than that computed during the original estimation. The model can only be refit if the data have not changed.

Remarks and examples

Remarks are presented under the following headings:

estat abond
estat sargan

estat abond

The moment conditions used by `xtdpd` are valid only if there is no serial correlation in the idiosyncratic errors. Testing for serial correlation in dynamic panel-data models is tricky because one needs to apply a transform to remove the panel-level effects, but the transformed errors have a more complicated error structure than the idiosyncratic errors. The Arellano–Bond test for serial correlation reported by `estat abond` tests for serial correlation in the first-differenced errors.

Because the first difference of independently and identically distributed idiosyncratic errors will be autocorrelated, rejecting the null hypothesis of no serial correlation at order one in the first-differenced errors does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [example 5](#) in [\[XT\] xtdpd](#) for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified.

estat sargan

Like all GMM estimators, the estimator in `xtdpd` can produce consistent estimates only if the moment conditions used are valid. Although there is no method to test if the moment conditions from an exactly identified model are valid, one can test whether the overidentifying moment conditions are valid. `estat sargan` implements the Sargan test of overidentifying conditions discussed in [Arellano and Bond \(1991\)](#).

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, `xtdpd` does not compute it when `vce(robust)` is specified.

Methods and formulas

The notation for $\hat{\epsilon}_{1i}^*$, $\hat{\epsilon}_{1i}$, \mathbf{H}_{1i} , \mathbf{H}_{2i} , \mathbf{X}_i , \mathbf{Z}_i , \mathbf{W}_1 , \mathbf{W}_2 , $\hat{\mathbf{V}}_*[\hat{\beta}_*]$, \mathbf{A}_1 , \mathbf{A}_2 , \mathbf{Q}_{xz} , and $\hat{\sigma}_1^2$ has been defined in [Methods and formulas](#) of [\[XT\] xtdpd](#).

The Arellano–Bond test for zero m th-order autocorrelation in the first-differenced errors is given by

$$A(m) = \frac{s_0}{\sqrt{s_1 + s_2 + s_3}}$$

where the definitions of s_0 , s_1 , s_2 , and s_3 vary over the estimators and transforms.

We begin by defining $\hat{\mathbf{u}}_{1i}^* = Lm.\hat{\epsilon}_{1i}^*$, with the missing values filled in with zeros. Letting $j = 1$ for the one-step estimator, $j = 2$ for the two-step estimator, $c = \text{GMM}$ for the GMM VCE estimator, and $c = \text{robust}$ for the robust VCE estimator, we can now define s_0 , s_1 , s_2 , and s_3 :

$$s_0 = \sum_i \hat{\mathbf{u}}_{ji}^{*'} \hat{\epsilon}_{ji}^*$$

$$s_1 = \sum_i \hat{\mathbf{u}}_{ji}^{*'} \mathbf{H}_{ji} \hat{\mathbf{u}}_{ji}^*$$

$$s_2 = -2\mathbf{q}_{ji} \mathbf{W}_j^{-1} \mathbf{Q}_{xz} \mathbf{A}_j \mathbf{Q}_{zu}$$

$$s_3 = \mathbf{q}_{jx} \widehat{\mathbf{V}}_c \left[\widehat{\boldsymbol{\beta}}_j \right] \mathbf{q}'_{jx}$$

where

$$\mathbf{q}_{jx} = \left(\sum_i \widehat{\mathbf{u}}_{ji}^{*'} \mathbf{x}_i \right)$$

and \mathbf{Q}_{zu} varies over estimator and transform.

For the Arellano–Bond estimator with the first-differenced transform,

$$\mathbf{Q}_{zu} = \left(\sum_i \mathbf{Z}'_i \mathbf{H}_{ji} \widehat{\mathbf{u}}_{ji}^* \right)$$

For the Arellano–Bond estimator with the FOD transform,

$$\mathbf{Q}_{zu} = \left(\sum_i \mathbf{Z}'_i \mathbf{Q}_{\text{fod}} \right)$$

where

$$\mathbf{Q}_{\text{fod}} = \begin{pmatrix} -\sqrt{\frac{T_i+1}{T_i}} & 0 & \cdots & 0 \\ \sqrt{\frac{T_i-1}{T_i}} & \sqrt{\frac{T_i}{T_i-1}} & \cdots & 0 \\ 0 & \cdot & \ddots & \vdots \\ 0 & \cdots & \sqrt{\frac{1}{2}} & -\sqrt{\frac{2}{1}} \end{pmatrix} \widehat{\mathbf{u}}_{ji}^*$$

and * implies the first-differenced transform instead of the FOD transform.

For the Arellano–Bover/Blundell–Bond system estimator with the first-differenced transform,

$$\mathbf{Q}_{zu} = \left(\sum_i \mathbf{Z}'_i \widehat{\boldsymbol{\epsilon}}_{ji} \widehat{\boldsymbol{\epsilon}}_{ji}^{*'} \widehat{\mathbf{u}}_{ji}^* \right)$$

After a one-step estimator, the Sargan test is

$$S_1 = \frac{1}{\widehat{\sigma}_1^2} \left(\sum_i \widehat{\epsilon}_{1i}' \mathbf{Z}_i \right) \mathbf{A}_1 \left(\sum_i \mathbf{Z}_i' \widehat{\epsilon}_{1i} \right)$$

The transformed two-step residuals are given by

$$\widehat{\epsilon}_{2i}^* = \mathbf{y}_i^* - \widehat{\beta}_2 \mathbf{X}_i^*$$

and the level two-step residuals are given by

$$\widehat{\epsilon}_{2i}^L = \mathbf{y}_i^L - \widehat{\beta}_2 \mathbf{X}_i^L$$

Stacking the residual vectors yields

$$\widehat{\epsilon}_{2i} = \begin{pmatrix} \widehat{\epsilon}_{2i}^* \\ \widehat{\epsilon}_{2i}^L \end{pmatrix}$$

After a two-step estimator, the Sargan test is

$$S_2 = \left(\sum_i \widehat{\epsilon}_{2i}' \mathbf{Z}_i \right) \mathbf{A}_2 \left(\sum_i \mathbf{Z}_i' \widehat{\epsilon}_{2i} \right)$$

Reference

Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.

Also see

[XT] [xtdpd](#) — Linear dynamic panel-data estimation

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	Acknowledgment
References	Also see		

Syntax

xtdpdsys *depvar* [*indepvars*] [*if*] [*in*] [, *options*]

<i>options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>lags</u> (#)	use # lags of dependent variable as covariates; default is <code>lags(1)</code>
<u>maxldep</u> (#)	maximum lags of dependent variable for use as instruments
<u>maxlags</u> (#)	maximum lags of predetermined and endogenous variables for use as instruments
<u>twostep</u>	compute the two-step estimator instead of the one-step estimator
Predetermined	
<u>pre</u> (<i>varlist</i> [...])	predetermined variables; can be specified more than once
Endogenous	
<u>endogenous</u> (<i>varlist</i> [...])	endogenous variables; can be specified more than once
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <code>gmm</code> or <code>robust</code>
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>artests</u> (#)	use # as maximum order for AR tests; default is <code>artests(2)</code>
<i>display_options</i>	control spacing and line width
<u>coeflegend</u>	display legend instead of statistics

A panel variable and a time variable must be specified; use [XT] `xtset`.
indepvars and all *varlists*, except `pre(varlist[...])` and `endogenous(varlist[...])`, may contain time-series operators; see [U] 11.4.4 Time-series varlists. The specification of *depvar* may not contain time-series operators.
by, *statsby*, and *xi* are allowed; see [U] 11.1.10 Prefix commands.
`coeflegend` does not appear in the dialog box.
See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Arellano-Bover/Blundell-Bond estimation

Description

Linear dynamic panel-data models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. [Arellano and Bond \(1991\)](#) derived a consistent generalized method of moments (GMM) estimator for this model. The Arellano and Bond estimator can perform poorly if the autoregressive parameters are too large or the ratio of the variance of the panel-level effect to the variance of idiosyncratic error is too large. Building on the work of [Arellano and Bover \(1995\)](#), [Blundell and Bond \(1998\)](#) developed a system estimator that uses additional moment conditions; `xtdpdsys` implements this estimator.

This estimator is designed for datasets with many panels and few periods. This method assumes that there is no autocorrelation in the idiosyncratic errors and requires the initial condition that the panel-level effects be uncorrelated with the first difference of the first observation of the dependent variable.

Options

Model

`noconstant`; see [\[R\] estimation options](#).

`lags(#)` sets p , the number of lags of the dependent variable to be included in the model. The default is $p = 1$.

`maxldep(#)` sets the maximum number of lags of the dependent variable that can be used as instruments. The default is to use all $T_i - p - 2$ lags.

`maxlags(#)` sets the maximum number of lags of the predetermined and endogenous variables that can be used as instruments. For predetermined variables, the default is to use all $T_i - p - 1$ lags. For endogenous variables, the default is to use all $T_i - p - 2$ lags.

`twostep` specifies that the two-step estimator be calculated.

Predetermined

`pre(varlist [, lagstruct(prelags, premaxlags))` specifies that a set of predetermined variables be included in the model. Optionally, you may specify that *prelags* lags of the specified variables also be included. The default for *prelags* is 0. Specifying *premaxlags* sets the maximum number of further lags of the predetermined variables that can be used as instruments. The default is to include $T_i - p - 1$ lagged levels as instruments for predetermined variables. You may specify as many sets of predetermined variables as you need within the standard Stata limits on matrix size. Each set of predetermined variables may have its own number of *prelags* and *premaxlags*.

Endogenous

`endogenous(varlist [, lagstruct(endlags, endmaxlags))` specifies that a set of endogenous variables be included in the model. Optionally, you may specify that *endlags* lags of the specified variables also be included. The default for *endlags* is 0. Specifying *endmaxlags* sets the maximum number of further lags of the endogenous variables that can be used as instruments. The default is to include $T_i - p - 2$ lagged levels as instruments for endogenous variables. You may specify as many sets of endogenous variables as you need within the standard Stata limits on matrix size. Each set of endogenous variables may have its own number of *endlags* and *endmaxlags*.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see [Methods and formulas](#) in [XT] **xtdpd**.

`vce(gmm)`, the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

`vce(robust)` uses the robust estimator. For the one-step estimator, this is the Arellano–Bond robust VCE estimator. For the two-step estimator, this is the [Windmeijer \(2005\)](#) WC-robust estimator.

Reporting

`level(#)`; see [R] [estimation options](#).

`artests(#)` specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by `estat abond`; see [XT] **xtdpdsys postestimation**. Specifying the order of the highest test at estimation time is more efficient than specifying it to `estat abond`, because `estat abond` must refit the model to obtain the test statistics. The maximum order must be less than or equal the number of periods in the longest panel. The default is `artests(2)`.

display_options: `vsquish` and `nolstretch`; see [R] [estimation options](#).

The following option is available with **xtdpdsys** but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

If you have not read [XT] **xtabond**, you may want to do so before continuing.

Consider the dynamic panel-data model

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it} \beta_1 + \mathbf{w}_{it} \beta_2 + \nu_i + \epsilon_{it} \quad i = 1, \dots, N \quad t = 1, \dots, T_i \quad (1)$$

where

the α_j are p parameters to be estimated,

\mathbf{x}_{it} is a $1 \times k_1$ vector of strictly exogenous covariates,

β_1 is a $k_1 \times 1$ vector of parameters to be estimated,

\mathbf{w}_{it} is a $1 \times k_2$ vector of predetermined or endogenous covariates,

β_2 is a $k_2 \times 1$ vector of parameters to be estimated,

ν_i are the panel-level effects (which may be correlated with the covariates), and

ϵ_{it} are i.i.d. over the whole sample with variance σ_ϵ^2 .

The ν_i and the ϵ_{it} are assumed to be independent for each i over all t .

By construction, the lagged dependent variables are correlated with the unobserved panel-level effects, making standard estimators inconsistent. With many panels and few periods, the Arellano–Bond estimator is constructed by first-differencing to remove the panel-level effects and using instruments to form moment conditions.

Blundell and Bond (1998) show that the lagged-level instruments in the Arellano–Bond estimator become weak as the autoregressive process becomes too persistent or the ratio of the variance of the panel-level effects ν_i to the variance of the idiosyncratic error ϵ_{it} becomes too large. Building on the work of Arellano and Bover (1995), Blundell and Bond (1998) proposed a system estimator that uses moment conditions in which lagged differences are used as instruments for the level equation in addition to the moment conditions of lagged levels as instruments for the differenced equation. The additional moment conditions are valid only if the initial condition $E[\nu_i \Delta y_{i2}] = 0$ holds for all i ; see Blundell and Bond (1998) and Blundell, Bond, and Windmeijer (2000).

xtdpdsys fits dynamic panel-data estimators with the Arellano–Bover/Blundell–Bond system estimator. Because xtdpdsys extends xtabond, [XT] xtabond provides useful background.

▶ Example 1: A dynamic panel model

In their article, Arellano and Bond (1991) apply their estimators and test statistics to a model of dynamic labor demand that had previously been considered by Layard and Nickell (1986), using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm i and time t . In this dataset, n_{it} is the log of employment in firm i at time t , w_{it} is the natural log of the real product wage, k_{it} is the natural log of the gross capital stock, and ys_{it} is the natural log of industry output. The model also includes time dummies yr1980, yr1981, yr1982, yr1983, and yr1984.

For comparison, we begin by using xtabond to fit a model to these data.


```
. use http://www.stata-press.com/data/r13/abdata
. xtabond n L(0/2).(w k) yr1980-yr1984 year, vce(robust)
Arellano-Bond dynamic panel-data estimation   Number of obs       =       611
Group variable: id                           Number of groups      =       140
Time variable: year
Obs per group:   min =          4
                  avg =   4.364286
                  max =          6
Number of instruments =      40                Wald chi2(13)         =   1318.68
                                                Prob > chi2          =    0.0000
```

One-step results
(Std. Err. adjusted for clustering on id)

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6286618	.1161942	5.41	0.000	.4009254	.8563983
w						
--.	-.5104249	.1904292	-2.68	0.007	-.8836592	-.1371906
L1.	.2891446	.140946	2.05	0.040	.0128954	.5653937
L2.	-.0443653	.0768135	-0.58	0.564	-.194917	.1061865
k						
--.	.3556923	.0603274	5.90	0.000	.2374528	.4739318
L1.	-.0457102	.0699732	-0.65	0.514	-.1828552	.0914348
L2.	-.0619721	.0328589	-1.89	0.059	-.1263743	.0024301
yr1980	-.0282422	.0166363	-1.70	0.090	-.0608488	.0043643
yr1981	-.0694052	.028961	-2.40	0.017	-.1261677	-.0126426
yr1982	-.0523678	.0423433	-1.24	0.216	-.1353591	.0306235
yr1983	-.0256599	.0533747	-0.48	0.631	-.1302723	.0789525
yr1984	-.0093229	.0696241	-0.13	0.893	-.1457837	.1271379
year	.0019575	.0119481	0.16	0.870	-.0214604	.0253754
_cons	-2.543221	23.97919	-0.11	0.916	-49.54158	44.45514

Instruments for differenced equation
GMM-type: L(2/.)n
Standard: D.w LD.w L2D.w D.k LD.k L2D.k D.yr1980 D.yr1981 D.yr1982
D.yr1983 D.yr1984 D.year
Instruments for level equation
Standard: _cons

Now we fit the same model by using xtdpdsys:

```
. xtdpdsys n L(0/2).(w k) yr1980-yr1984 year, vce(robust)
System dynamic panel-data estimation      Number of obs      =      751
Group variable: id                      Number of groups    =      140
Time variable: year

Obs per group:      min =      5
                   avg =  5.364286
                   max =      7

Number of instruments =      47          Wald chi2(13)      =  2579.96
                                           Prob > chi2        =   0.0000

One-step results
```

	n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
n						
L1.		.8221535	.093387	8.80	0.000	.6391184 1.005189
w						
--.		-.5427935	.1881721	-2.88	0.004	-.911604 -.1739831
L1.		.3703602	.1656364	2.24	0.025	.0457189 .6950015
L2.		-.0726314	.0907148	-0.80	0.423	-.2504292 .1051664
k						
--.		.3638069	.0657524	5.53	0.000	.2349346 .4926792
L1.		-.1222996	.0701521	-1.74	0.081	-.2597951 .015196
L2.		-.0901355	.0344142	-2.62	0.009	-.1575862 -.0226849
yr1980		-.0308622	.016946	-1.82	0.069	-.0640757 .0023512
yr1981		-.0718417	.0293223	-2.45	0.014	-.1293123 -.014371
yr1982		-.0384806	.0373631	-1.03	0.303	-.1117111 .0347498
yr1983		-.0121768	.0498519	-0.24	0.807	-.1098847 .0855311
yr1984		-.0050903	.0655011	-0.08	0.938	-.1334701 .1232895
year		.0058631	.0119867	0.49	0.625	-.0176304 .0293566
_cons		-10.59198	23.92087	-0.44	0.658	-57.47602 36.29207

```
Instruments for differenced equation
GMM-type: L(2/.)n
Standard: D.w LD.w L2D.w D.k LD.k L2D.k D.yr1980 D.yr1981 D.yr1982
          D.yr1983 D.yr1984 D.year
Instruments for level equation
GMM-type: LD.n
Standard: _cons
```

If you are unfamiliar with the `L()` `()` notation, see [U] 13.9 Time-series operators. That the system estimator produces a much higher estimate of the coefficient on lagged employment agrees with the results in Blundell and Bond (1998), who show that the system estimator does not have the downward bias that the Arellano–Bond estimator has when the true value is high.

Comparing the footers illustrates the difference between the two estimators; xtdpdsys includes lagged differences of `n` as instruments for the level equation, whereas xtabond does not. Comparing the headers shows that xtdpdsys has seven more instruments than xtabond. (As it should; there are 7 observations on `LD.n` available in the complete panels that run from 1976–1984, after accounting for the first two years that are lost because the model has two lags.) Only the first lags of the variables are used because the moment conditions using higher lags are redundant; see Blundell and Bond (1998) and Blundell, Bond, and Windmeijer (2000).

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced errors. The moment conditions are valid only if there is no serial correlation in the idiosyncratic errors.

Because the first difference of independently and identically distributed idiosyncratic errors will be autocorrelated, rejecting the null hypothesis of no serial correlation at order one in the first-differenced errors does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [XT] **xtdpd** for an alternative estimator in this case.

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-4.6414	0.0000
2	-1.0572	0.2904

HO: no autocorrelation

The above output does not present evidence that the model is misspecified.



► **Example 2: Including predetermined covariates**

Sometimes we cannot assume strict exogeneity. Recall that a variable x_{it} is said to be strictly exogenous if $E[x_{it}\epsilon_{is}] = 0$ for all t and s . If $E[x_{it}\epsilon_{is}] \neq 0$ for $s < t$ but $E[x_{it}\epsilon_{is}] = 0$ for all $s \geq t$, the variable is said to be predetermined. Intuitively, if the error term at time t has some feedback on the subsequent realizations of x_{it} , x_{it} is a predetermined variable. Because unforecastable errors today might affect future changes in the real wage and in the capital stock, we might suspect that the log of the real product wage and the log of the gross capital stock are predetermined instead of strictly exogenous.


```
. xtdpdpsys n yr1980-yr1984 year, pre(w k, lag(2, .)) vce(robust)
System dynamic panel-data estimation      Number of obs      =      751
Group variable: id                       Number of groups    =      140
Time variable: year

Obs per group:   min =      5
                  avg =  5.364286
                  max =      7

Number of instruments =      95           Wald chi2(13)       =    7562.80
                                           Prob > chi2         =     0.0000
```

One-step results

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.913278	.0460602	19.83	0.000	.8230017	1.003554
w						
--.	-.728159	.1019044	-7.15	0.000	-.927888	-.5284301
L1.	.5602737	.1939617	2.89	0.004	.1801156	.9404317
L2.	-.0523028	.1487653	-0.35	0.725	-.3438775	.2392718
k						
--.	.4820097	.0760787	6.34	0.000	.3328983	.6311212
L1.	-.2846944	.0831902	-3.42	0.001	-.4477442	-.1216446
L2.	-.1394181	.0405709	-3.44	0.001	-.2189356	-.0599006
yr1980	-.0325146	.0216371	-1.50	0.133	-.0749226	.0098935
yr1981	-.0726116	.0346482	-2.10	0.036	-.1405207	-.0047024
yr1982	-.0477038	.0451914	-1.06	0.291	-.1362772	.0408696
yr1983	-.0396264	.0558734	-0.71	0.478	-.1491362	.0698835
yr1984	-.0810383	.0736648	-1.10	0.271	-.2254186	.063342
year	.0192741	.0145326	1.33	0.185	-.0092092	.0477574
_cons	-37.34972	28.77747	-1.30	0.194	-93.75253	19.05308

```
Instruments for differenced equation
GMM-type: L(2/.)n L(1/.)L2.w L(1/.)L2.k
Standard: D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year
Instruments for level equation
GMM-type: LD.n L2D.w L2D.k
Standard: _cons
```

The footer informs us that we are now including GMM-type instruments from the first lag of L.w on back and from the first lag of L2.k on back for the differenced errors and the second lags of the differences of w and k as instruments for the level errors.



□ Technical note

The above example illustrates that xtdpdpsys understands `pre(w k, lag(2, .))` to mean that L2.w and L2.k are predetermined variables. This is a stricter definition than the alternative that `pre(w k, lag(2, .))` means only that w k are predetermined but to include two lags of w and two lags of k in the model. If you prefer the weaker definition, xtdpdpsys still gives you consistent estimates, but it is not using all possible instruments; see [XT] [xtdpd](#) for an [example](#) of how to include all possible instruments.



Stored results

`xtdpdsys` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	χ^2
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of σ_ϵ^2
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

Macros

<code>e(cmd)</code>	<code>xtdpdsys</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(twostep)</code>	<code>twostep</code> , if specified
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(system)</code>	<code>system</code> , if system estimator
<code>e(hascons)</code>	<code>hascons</code> , if specified
<code>e(transform)</code>	specified transform
<code>e(datasignature)</code>	checksum from <code>datasignature</code>
<code>e(properties)</code>	<code>b V</code>
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtdpdsys` uses `xtdpd` to perform its computations, so the formulas are given in [Methods and formulas](#) of [XT] `xtdpd`.

Acknowledgment

We thank David Roodman of the Center for Global Development, who wrote `xtabond2`.

References

- Anderson, T. W., and C. Hsiao. 1981. Estimation of dynamic models with error components. *Journal of the American Statistical Association* 76: 598–606.
- . 1982. Formulation and estimation of dynamic models using panel data. *Journal of Econometrics* 18: 47–82.
- Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.
- Arellano, M., and O. Bover. 1995. Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics* 68: 29–51.
- Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Blackburne, E. F., III, and M. W. Frank. 2007. Estimation of nonstationary heterogeneous panels. *Stata Journal* 7: 197–208.
- Blundell, R., and S. Bond. 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87: 115–143.
- Blundell, R., S. Bond, and F. Windmeijer. 2000. Estimation in dynamic panel data models: Improving on the performance of the standard GMM estimator. In *Nonstationary Panels, Cointegrating Panels and Dynamic Panels*, ed. B. H. Baltagi, 53–92. New York: Elsevier.
- Bruno, G. S. F. 2005. Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *Stata Journal* 5: 473–500.
- Hansen, L. P. 1982. Large sample properties of generalized method of moments estimators. *Econometrica* 50: 1029–1054.
- Holtz-Eakin, D., W. K. Newey, and H. S. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* 56: 1371–1395.
- Layard, R., and S. J. Nickell. 1986. Unemployment in Britain. *Economica* 53: S121–S169.
- Windmeijer, F. 2005. A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics* 126: 25–51.

Also see

- [XT] **xtdpdsys postestimation** — Postestimation tools for xtdpdsys
- [XT] **xtset** — Declare data to be panel data
- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [XT] **xtdpd** — Linear dynamic panel-data estimation
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [U] **20 Estimation and postestimation commands**

Description	Syntax for predict	Menu for predict
Options for predict	Syntax for estat	Menu for estat
Option for estat abond	Remarks and examples	Methods and formulas
Reference	Also see	

Description

The following postestimation commands are of special interest after `xtdpdsys`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Special-interest postestimation commands

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced residuals.
`estat sargan` reports the Sargan test of the overidentifying restrictions.

Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

e calculates the residual error.

stdp calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. **stdp** may not be combined with **difference**.

difference specifies that the statistic be calculated for the first differences instead of the levels, the default.

Syntax for estat

Test for autocorrelation

```
estat abond [, artests(#)]
```

Sargan test of overidentifying restrictions

```
estat sargan
```

Menu for estat

Statistics > Postestimation > Reports and statistics

Option for estat abond

artests(#) specifies highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when **artests(#)** specifies a higher order than that computed during the original estimation. The model can only be refit if the data have not changed.

Remarks and examples

Remarks are presented under the following headings:

estat abond
estat sargan

estat abond

The moment conditions used by `xtdpdsys` are valid only if there is no serial correlation in the idiosyncratic errors. Testing for serial correlation in dynamic panel-data models is tricky because a transform is required to remove the panel-level effects, but the transformed errors have a more complicated error structure than that of the idiosyncratic errors. The Arellano–Bond test for serial correlation reported by `estat abond` tests for serial correlation in the first-differenced errors.

Because the first difference of independently and identically distributed idiosyncratic errors will be serially correlated, rejecting the null hypothesis of no serial correlation in the first-differenced errors at order one does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [example 5](#) in [\[XT\] xtdpd](#) for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified.

estat sargan

Like all GMM estimators, the estimator in `xtdpdsys` can produce consistent estimates only if the moment conditions used are valid. Although there is no method to test if the moment conditions from an exactly identified model are valid, one can test whether the overidentifying moment conditions are valid. `estat sargan` implements the Sargan test of overidentifying conditions discussed in [Arellano and Bond \(1991\)](#).

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, `xtdpdsys` does not compute it when `vce(robust)` is specified. See [\[XT\] xtdpd](#) for an [example](#) in which the null hypothesis of the Sargan test is not rejected.

```
. use http://www.stata-press.com/data/r13/abdata
. xtdpdsys n L(0/2).(w k) yr1980-yr1984 year
  (output omitted)
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
      chi2(33)      =   63.63911
      Prob > chi2    =    0.0011
```

The output above presents strong evidence against the null hypothesis that the overidentifying restrictions are valid. Rejecting this null hypothesis implies that we need to reconsider our model or our instruments, unless we attribute the rejection to heteroskedasticity in the data-generating process. Although performing the Sargan test after the two-step estimator is an alternative, [Arellano and Bond \(1991\)](#) found a tendency for this test to underreject in the presence of heteroskedasticity.

Methods and formulas

The formulas are given in [Methods and formulas](#) of [\[XT\] xtdpd postestimation](#).

Reference

Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.

Also see

[XT] [xtdpdsys](#) — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu
Description	Options for time-invariant model
Options for time-varying decay model	Remarks and examples
Stored results	Methods and formulas
References	Also see

Syntax

Time-invariant model

```
xtfrontier depvar [indepvars] [if] [in] [weight] , ti [ti_options]
```

Time-varying decay model

```
xtfrontier depvar [indepvars] [if] [in] [weight] , tvd [tvd_options]
```

ti_options	Description
Model	
<u>noconstant</u>	suppress constant term
<u>ti</u>	use time-invariant model
<u>cost</u>	fit cost frontier model
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <code>oim</code> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>nocnsreport</u>	do not display constraints
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<i>maximize_options</i>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>tvd_options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>tvd</code>	use time-varying decay model
<code>cost</code>	fit cost frontier model
<code>constraints(<i>constraints</i>)</code>	apply specified linear constraints
<code>collinear</code>	keep collinear variables
SE	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>oim</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>nocnsreport</code>	do not display constraints
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<code>maximize_options</code>	control the maximization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified. For `xtfrontier`, `tvd`, a time variable must also be specified. Use `xtset`; see [\[XT\] xtset](#).

indevars may contain factor variables; see [\[U\] 11.4.3 Factor variables](#).

depar and *indevars* may contain time-series operators; see [\[U\] 11.4.4 Time-series varlists](#).

`by`, `fp`, and `statsby` are allowed; see [\[U\] 11.1.10 Prefix commands](#).

`fweights` and `iweights` are allowed; see [\[U\] 11.1.6 weight](#). Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [\[U\] 20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Frontier models

Description

`xtfrontier` fits stochastic production or cost frontier models for panel data. More precisely, `xtfrontier` estimates the parameters of a linear model with a disturbance generated by specific mixture distributions.

The disturbance term in a stochastic frontier model is assumed to have two components. One component is assumed to have a strictly nonnegative distribution, and the other component is assumed to have a symmetric distribution. In the econometrics literature, the nonnegative component is often referred to as the *inefficiency term*, and the component with the symmetric distribution as the *idiosyncratic error*. `xtfrontier` permits two different parameterizations of the inefficiency term: a time-invariant model and the Battese–Coelli (1992) parameterization of time effects. In the time-invariant model, the inefficiency term is assumed to have a truncated-normal distribution. In the Battese–Coelli (1992) parameterization of time effects, the inefficiency term is modeled as a truncated-normal random variable multiplied by a specific function of time. In both models, the

idiosyncratic error term is assumed to have a normal distribution. The only panel-specific effect is the random inefficiency term.

See [Kumbhakar and Lovell \(2000\)](#) for a detailed introduction to frontier analysis.

Options for time-invariant model

Model

`noconstant`; see [\[R\] estimation options](#).

`ti` specifies that the parameters of the time-invariant technical inefficiency model be estimated.

`cost` specifies that the frontier model be fit in terms of a cost function instead of a production function. By default, `xtfrontier` fits a production frontier model.

`constraints(constraints)`, `collinear`; see [\[R\] estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

Reporting

`level(#)`; see [\[R\] estimation options](#).

`nocnsreport`; see [\[R\] estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [\[R\] maximize](#). These options are seldom used.

The following option is available with `xtfrontier` but is not shown in the dialog box:

`coeflegend`; see [\[R\] estimation options](#).

Options for time-varying decay model

Model

`noconstant`; see [\[R\] estimation options](#).

`tvd` specifies that the parameters of the time-varying decay model be estimated.

`cost` specifies that the frontier model be fit in terms of a cost function instead of a production function. By default, `xtfrontier` fits a production frontier model.

`constraints(constraints)`, `collinear`; see [\[R\] estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`nocnsreport`; see [R] [estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtfrontier` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

Remarks are presented under the following headings:

[Introduction](#)

[Time-invariant model](#)

[Time-varying decay model](#)

Introduction

Stochastic production frontier models were introduced by [Aigner, Lovell, and Schmidt \(1977\)](#) and [Meeusen and van den Broeck \(1977\)](#). Since then, stochastic frontier models have become a popular subfield in econometrics; see [Kumbhakar and Lovell \(2000\)](#) for an introduction. `xtfrontier` fits two stochastic frontier models with distinct specifications of the inefficiency term and can fit both production- and cost-frontier models.

Let's review the nature of the stochastic frontier problem. Suppose that a producer has a production function $f(\mathbf{z}_{it}, \beta)$. In a world without error or inefficiency, in time t , the i th firm would produce

$$q_{it} = f(\mathbf{z}_{it}, \beta)$$

A fundamental element of stochastic frontier analysis is that each firm potentially produces less than it might because of a degree of inefficiency. Specifically,

$$q_{it} = f(\mathbf{z}_{it}, \beta)\xi_{it}$$

where ξ_{it} is the level of efficiency for firm i at time t ; ξ_i must be in the interval $(0, 1]$. If $\xi_{it} = 1$, the firm is achieving the optimal output with the technology embodied in the production function $f(\mathbf{z}_{it}, \beta)$. When $\xi_{it} < 1$, the firm is not making the most of the inputs \mathbf{z}_{it} given the technology embodied in the production function $f(\mathbf{z}_{it}, \beta)$. Because the output is assumed to be strictly positive (that is, $q_{it} > 0$), the degree of technical efficiency is assumed to be strictly positive (that is, $\xi_{it} > 0$).

Output is also assumed to be subject to random shocks, implying that

$$q_{it} = f(\mathbf{z}_{it}, \beta) \xi_{it} \exp(v_{it})$$

Taking the natural log of both sides yields

$$\ln(q_{it}) = \ln\{f(\mathbf{z}_{it}, \beta)\} + \ln(\xi_{it}) + v_{it}$$

Assuming that there are k inputs and that the production function is linear in logs, defining $u_{it} = -\ln(\xi_{it})$ yields

$$\ln(q_{it}) = \beta_0 + \sum_{j=1}^k \beta_j \ln(z_{jit}) + v_{it} - u_{it} \quad (1)$$

Because u_{it} is subtracted from $\ln(q_{it})$, restricting $u_{it} \geq 0$ implies that $0 < \xi_{it} \leq 1$, as specified above.

Kumbhakar and Lovell (2000) provide a detailed version of this derivation, and they show that performing an analogous derivation in the dual cost function problem allows us to specify the problem as

$$\ln(c_{it}) = \beta_0 + \beta_q \ln(q_{it}) + \sum_{j=1}^k \beta_j \ln(p_{jit}) + v_{it} - s u_{it} \quad (2)$$

where q_{it} is output, the z_{jit} are input quantities, c_{it} is cost, the p_{jit} are input prices, and

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

Intuitively, the inefficiency effect is required to lower output or raise expenditure, depending on the specification.

□ Technical note

The model that `xtfrontier` actually fits has the form

$$y_{it} = \beta_0 + \sum_{j=1}^k \beta_j x_{jit} + v_{it} - s u_{it}$$

so in the context of the discussion above, $y_{it} = \ln(q_{it})$ and $x_{jit} = \ln(z_{jit})$ for a production function; for a cost function, $y_{it} = \ln(c_{it})$, the x_{jit} are the $\ln(p_{jit})$, and $\ln(q_{it})$. You must perform the natural logarithm transformation of the data before estimation to interpret the estimation results correctly for a stochastic frontier production or cost model. `xtfrontier` does not perform any transformations on the data.

□

Equation (2) is a variant of a panel-data model in which v_{it} is the idiosyncratic error and u_{it} is a time-varying panel-level effect. Much of the literature on this model has focused on deriving estimators for different specifications of the u_{it} term. Kumbhakar and Lovell (2000) provide a survey of this literature.

`xtfrontier` provides estimators for two different specifications of u_{it} . To facilitate the discussion, let $N^+(\mu, \sigma^2)$ denote the truncated-normal distribution, which is truncated at zero with mean μ and variance σ^2 , and let $\overset{\text{iid}}{\sim}$ stand for independently and identically distributed.

Consider the simplest specification in which u_{it} is a time-invariant truncated-normal random variable. In the time-invariant model, $u_{it} = u_i$, $u_i \overset{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$, $v_{it} \overset{\text{iid}}{\sim} N(0, \sigma_v^2)$, and u_i and v_{it} are distributed independently of each other and the covariates in the model. Specifying the `ti` option causes `xtfrontier` to estimate the parameters of this model.

In the time-varying decay specification,

$$u_{it} = \exp\{-\eta(t - T_i)\}u_i$$

where T_i is the last period in the i th panel, η is the decay parameter, $u_i \overset{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$, $v_{it} \overset{\text{iid}}{\sim} N(0, \sigma_v^2)$, and u_i and v_{it} are distributed independently of each other and the covariates in the model. Specifying the `tvd` option causes `xtfrontier` to estimate the parameters of this model.

Time-invariant model

► Example 1

`xtfrontier`, `ti` provides maximum likelihood estimates for the parameters of the time-invariant decay model. In this model, the inefficiency effects are modeled as $u_{it} = u_i$, $u_i \overset{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$, $v_{it} \overset{\text{iid}}{\sim} N(0, \sigma_v^2)$, and u_i and v_{it} are distributed independently of each other and the covariates in the model. In this example, firms produce a product called a widget, using a constant-returns-to-scale technology. We have 948 observations—91 firms, with 6–14 observations per firm. Our dataset contains variables representing the quantity of widgets produced, the number of machine hours used in production, the number of labor hours used in production, and three additional variables that are the natural logarithm transformations of the three aforementioned variables.

We fit a time-invariant model using the transformed variables:

```
. use http://www.stata-press.com/data/r13/xtfrontier1
. xtfrontier lnwidgets lnmachines lnworkers, ti
Iteration 0:   log likelihood = -1473.8703
Iteration 1:   log likelihood = -1473.0565
Iteration 2:   log likelihood = -1472.6155
Iteration 3:   log likelihood = -1472.607
Iteration 4:   log likelihood = -1472.6069

Time-invariant inefficiency model
Group variable: id

Number of obs      =      948
Number of groups   =       91
Obs per group: min =        6
                  avg =     10.4
                  max =       14

Wald chi2(2)       =     661.76
Prob > chi2        =     0.0000

Log likelihood     = -1472.6069
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
lnmachines	.2904551	.0164219	17.69	0.000	.2582688	.3226415
lnworkers	.2943333	.0154352	19.07	0.000	.2640808	.3245858
_cons	3.030983	.1441022	21.03	0.000	2.748548	3.313418
/mu	1.125667	.6479217	1.74	0.082	-.144236	2.39557
/lnsigma2	1.421979	.2672745	5.32	0.000	.898131	1.945828
/ilgtgamma	1.138685	.3562642	3.20	0.001	.4404204	1.83695
sigma2	4.145318	1.107938			2.455011	6.999424
gamma	.7574382	.0654548			.6083592	.8625876
sigma_u2	3.139822	1.107235			.9696821	5.309962
sigma_v2	1.005496	.0484143			.9106055	1.100386

In addition to the coefficients, the output reports estimates for the parameters `sigma_v2`, `sigma_u2`, `gamma`, `sigma2`, `ilgtgamma`, `lnsigma2`, and `mu`. `sigma_v2` is the estimate of σ_v^2 . `sigma_u2` is the estimate of σ_u^2 . `gamma` is the estimate of $\gamma = \sigma_u^2 / \sigma_S^2$. `sigma2` is the estimate of $\sigma_S^2 = \sigma_v^2 + \sigma_u^2$. Because γ must be between 0 and 1, the optimization is parameterized in terms of the inverse logit of γ , and this estimate is reported as `ilgtgamma`. Because σ_S^2 must be positive, the optimization is parameterized in terms of $\ln(\sigma_S^2)$, and this estimate is reported as `lnsigma2`. Finally, `mu` is the estimate of μ .

❑ Technical note

Our simulation results indicate that this estimator requires relatively large samples to achieve any reasonable degree of precision in the estimates of μ and σ_u^2 .

Time-varying decay model

`xtfrontier`, `tvd` provides maximum likelihood estimates for the parameters of the time-varying decay model. In this model, the inefficiency effects are modeled as

$$u_{it} = \exp\{-\eta(t - T_i)\}u_i$$

where $u_i \overset{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$.

When $\eta > 0$, the degree of inefficiency decreases over time; when $\eta < 0$, the degree of inefficiency increases over time. Because $t = T_i$ in the last period, the last period for firm i contains the base level of inefficiency for that firm. If $\eta > 0$, the level of inefficiency decays toward the base level. If $\eta < 0$, the level of inefficiency increases to the base level.

► Example 2

When $\eta = 0$, the time-varying decay model reduces to the time-invariant model. The following example illustrates this property and demonstrates how to specify constraints and starting values in these models.

Let's begin by fitting the time-varying decay model on the same data that were used in the previous example for the time-invariant model.

```
. xtfrontier lnwidgets lnmachines lnworkers, tvd
Iteration 0:   log likelihood = -1551.3798   (not concave)
Iteration 1:   log likelihood = -1502.2637
Iteration 2:   log likelihood = -1476.3093   (not concave)
Iteration 3:   log likelihood = -1472.9845
Iteration 4:   log likelihood = -1472.5365
Iteration 5:   log likelihood = -1472.529
Iteration 6:   log likelihood = -1472.5289

Time-varying decay inefficiency model
Group variable: id
Time variable: t

Number of obs      =      948
Number of groups   =       91
Obs per group: min =        6
                  avg =     10.4
                  max =       14

Wald chi2(2)       =     661.93
Prob > chi2        =     0.0000

Log likelihood     = -1472.5289
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
lnmachines	.2907555	.0164376	17.69	0.000	.2585384	.3229725
lnworkers	.2942412	.0154373	19.06	0.000	.2639846	.3244978
_cons	3.028939	.1436046	21.09	0.000	2.74748	3.310399
/mu	1.110831	.6452809	1.72	0.085	-.1538967	2.375558
/eta	.0016764	.00425	0.39	0.693	-.0066535	.0100064
/lnsigma2	1.410723	.2679485	5.26	0.000	.885554	1.935893
/ilgtgamma	1.123982	.3584243	3.14	0.002	.4214828	1.82648
sigma2	4.098919	1.098299			2.424327	6.930228
gamma	.7547265	.0663495			.603838	.8613419
sigma_u2	3.093563	1.097606			.9422943	5.244832
sigma_v2	1.005356	.0484079			.9104785	1.100234

The estimate of η is close to zero, and the other estimates are not too far from those of the time-invariant model.

We can use `constraint` to constrain $\eta = 0$ and obtain the same results produced by the time-invariant model. Although there is only one statistical equation to be estimated in this model, the model fits five of Stata's [\[R\] ml](#) equations; see [\[R\] ml](#) or [Gould, Pitblado, and Poi \(2010\)](#). The equation names can be seen by listing the matrix of estimated coefficients.


```
. matrix list e(b)
e(b)[1,7]
      lnwidgets:  lnwidgets:  lnwidgets:  lnsigma2:  ilgtgamma:      mu:
      lnmachines  lnworkers   _cons      _cons      _cons      _cons
y1      .29075546   .2942412   3.0289395  1.4107233  1.1239816  1.1108307
      eta:
      _cons
y1      .00167642
```

To constrain a parameter to a particular value in any equation, except the first equation, you must specify both the equation name and the parameter name by using the syntax

```
constraint # [eqname]_b[varname] = value      or
constraint # [eqname]coefficient = value
```

where *eqname* is the equation name, *varname* is the name of the variable in a linear equation, and *coefficient* refers to any parameter that has been estimated. More elaborate specifications with expressions are possible; see the example with constant returns to scale below, and see [\[R\] constraint](#) for general reference.

Suppose that we impose the constraint $\eta = 0$; we get the same results as those reported above for the time-invariant model, except for some minute differences attributable to an alternate convergence path in the optimization.

```
. constraint 1 [eta]_cons = 0
. xtfrontier lnwidgets lnmachines lnworkers, tvd constraints(1)
Iteration 0:  log likelihood = -1540.7124 (not concave)
Iteration 1:  log likelihood = -1515.7726
Iteration 2:  log likelihood = -1473.0162
Iteration 3:  log likelihood = -1472.9223
Iteration 4:  log likelihood = -1472.6254
Iteration 5:  log likelihood = -1472.607
Iteration 6:  log likelihood = -1472.6069
Time-varying decay inefficiency model      Number of obs      =      948
Group variable: id                        Number of groups    =      91
Time variable: t                          Obs per group: min =      6
                                           avg =     10.4
                                           max =      14
                                           Wald chi2(2)       =     661.76
                                           Prob > chi2        =      0.0000
Log likelihood = -1472.6069
( 1)  [eta]_cons = 0
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
lnmachines	.2904551	.0164219	17.69	0.000	.2582688	.3226414
lnworkers	.2943332	.0154352	19.07	0.000	.2640807	.3245857
_cons	3.030963	.1440995	21.03	0.000	2.748534	3.313393
/mu	1.125507	.6480444	1.74	0.082	-.1446369	2.39565
/eta	0	(omitted)				
/lnsigma2	1.422039	.2673128	5.32	0.000	.8981155	1.945962
/ilgtgamma	1.138764	.3563076	3.20	0.001	.4404135	1.837114
sigma2	4.145565	1.108162			2.454972	7.000366
gamma	.7574526	.0654602			.6083575	.862607
sigma_u2	3.140068	1.107459			.9694878	5.310649
sigma_v2	1.005496	.0484143			.9106057	1.100386

Stored results

xtfrontier stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(g_min)</code>	minimum number of observations per group
<code>e(g_avg)</code>	average number of observations per group
<code>e(g_max)</code>	maximum number of observations per group
<code>e(sigma2)</code>	sigma2
<code>e(gamma)</code>	gamma
<code>e(Tcon)</code>	1 if panels balanced; 0 otherwise
<code>e(sigma_u)</code>	standard deviation of technical inefficiency
<code>e(sigma_v)</code>	standard deviation of random error
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	model significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtfrontier</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(function)</code>	production or cost
<code>e(model)</code>	ti, after time-invariant model; tvd, after time-varying decay model
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log (up to 20 iterations)
<code>e(V)</code>	variance-covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtfrontier` fits stochastic frontier models for panel data that can be expressed as

$$y_{it} = \beta_0 + \sum_{j=1}^k \beta_j x_{jit} + v_{it} - s u_{it}$$

where y_{it} is the natural logarithm of output, the x_{jit} are the natural logarithm of the input quantities for the production efficiency problem, y_{it} is the natural logarithm of costs, the x_{it} are the natural logarithm of input prices for the cost efficiency problem, and

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

For the time-varying decay model, the log-likelihood function is derived as

$$\begin{aligned} \ln L = & -\frac{1}{2} \left(\sum_{i=1}^N T_i \right) \{ \ln(2\pi) + \ln(\sigma_S^2) \} - \frac{1}{2} \sum_{i=1}^N (T_i - 1) \ln(1 - \gamma) \\ & - \frac{1}{2} \sum_{i=1}^N \ln \left\{ 1 + \left(\sum_{t=1}^{T_i} \eta_{it}^2 - 1 \right) \gamma \right\} - N \ln \{ 1 - \Phi(-\tilde{z}) \} - \frac{1}{2} N \tilde{z}^2 \\ & + \sum_{i=1}^N \ln \{ 1 - \Phi(-z_i^*) \} + \frac{1}{2} \sum_{i=1}^N z_i^{*2} - \frac{1}{2} \sum_{i=1}^N \sum_{t=1}^{T_i} \frac{\epsilon_{it}^2}{(1 - \gamma) \sigma_S^2} \end{aligned}$$

where $\sigma_S = (\sigma_u^2 + \sigma_v^2)^{1/2}$, $\gamma = \sigma_u^2 / \sigma_S^2$, $\epsilon_{it} = y_{it} - \mathbf{x}_{it}\boldsymbol{\beta}$, $\eta_{it} = \exp\{-\eta(t - T_i)\}$, $\tilde{z} = \mu / (\gamma \sigma_S^2)^{1/2}$, $\Phi()$ is the cumulative distribution function of the standard normal distribution, and

$$z_i^* = \frac{\mu(1 - \gamma) - s\gamma \sum_{t=1}^{T_i} \eta_{it} \epsilon_{it}}{\left[\gamma(1 - \gamma) \sigma_S^2 \left\{ 1 + \left(\sum_{t=1}^{T_i} \eta_{it}^2 - 1 \right) \gamma \right\} \right]^{1/2}}$$

Maximizing the above log likelihood estimates the coefficients η , μ , σ_v , and σ_u .

References

- Aigner, D. J., C. A. K. Lovell, and P. Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6: 21–37.
- Battese, G. E., and T. J. Coelli. 1992. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis* 3: 153–169.
- . 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20: 325–332.
- Belotti, F., S. Daidone, G. Ilardi, and V. Atella. 2013. Stochastic frontier analysis using Stata. *Stata Journal* 13: 719–758.
- Caudill, S. B., J. M. Ford, and D. M. Gropper. 1995. Frontier estimation and firm-specific inefficiency measures in the presence of heteroscedasticity. *Journal of Business and Economic Statistics* 13: 105–111.

- Coelli, T. J. 1995. Estimators and hypothesis tests for a stochastic frontier function: A Monte Carlo analysis. *Journal of Productivity Analysis* 6: 247–268.
- Coelli, T. J., D. S. P. Rao, C. J. O’Donnell, and G. E. Battese. 2005. *An Introduction to Efficiency and Productivity Analysis*. 2nd ed. New York: Springer.
- Gould, W. W., J. S. Pitblado, and B. P. Poi. 2010. *Maximum Likelihood Estimation with Stata*. 4th ed. College Station, TX: Stata Press.
- Kumbhakar, S. C., and C. A. K. Lovell. 2000. *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press.
- Meeusen, W., and J. van den Broeck. 1977. Efficiency estimation from Cobb–Douglas production functions with composed error. *International Economic Review* 18: 435–444.
- Zellner, A., and N. S. Revankar. 1969. Generalized production functions. *Review of Economic Studies* 36: 241–250.

Also see

- [XT] [xtfrontier postestimation](#) — Postestimation tools for xtfrontier
- [XT] [xtset](#) — Declare data to be panel data
- [R] [frontier](#) — Stochastic frontier models
- [U] [20 Estimation and postestimation commands](#)

Description
Remarks and examples

Syntax for predict
Methods and formulas

Menu for predict
Also see

Options for predict

Description

The following postestimation commands are available after `xtfrontier`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>u</code>	minus the natural log of the technical efficiency via $E(u_{it} \mid \epsilon_{it})$
<code>m</code>	minus the natural log of the technical efficiency via $M(u_{it} \mid \epsilon_{it})$
<code>te</code>	the technical efficiency via $E\{\exp(-su_{it}) \mid \epsilon_{it}\}$

where

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- `xb`, the default, calculates the linear prediction.
- `stdp` calculates the standard error of the linear prediction.
- `u` produces estimates of minus the natural log of the technical efficiency via $E(u_{it} \mid \epsilon_{it})$.
- `m` produces estimates of minus the natural log of the technical efficiency via the mode, $M(u_{it} \mid \epsilon_{it})$.
- `te` produces estimates of the technical efficiency via $E\{\exp(-su_{it}) \mid \epsilon_{it}\}$.

Remarks and examples

➤ Example 1

A production function exhibits *constant returns to scale* if doubling the amount of each input results in a doubling in the quantity produced. When the production function is linear in logs, constant returns to scale implies that the sum of the coefficients on the inputs is one. In [example 2](#) of [\[XT\] xtfrontier](#), we fit a time-varying decay model. Here we test whether the estimated production function exhibits constant returns:

```
. use http://www.stata-press.com/data/r13/xtfrontier1
. xtfrontier lnwidgets lnmachines lnworkers, tvd
  (output omitted)
. test lnmachines + lnworkers = 1
( 1)  [lnwidgets]lnmachines + [lnwidgets]lnworkers = 1
      chi2( 1) =   331.55
      Prob > chi2 =    0.0000
```

The test statistic is highly significant, so we reject the null hypothesis and conclude that this production function does not exhibit constant returns to scale.

The previous Wald χ^2 test indicated that the sum of the coefficients does not equal one. An alternative is to use `lincom` to compute the sum explicitly:

```
. lincom lnmachines + lnworkers
( 1)  [lnwidgets]lnmachines + [lnwidgets]lnworkers = 0
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
(1)	.5849967	.0227918	25.67	0.000	.5403256 .6296677

The sum of the coefficients is significantly less than one, so this production function exhibits *decreasing returns to scale*. If we doubled the number of machines and workers, we would obtain less than twice as much output.

◀

Methods and formulas

Continuing from the [Methods and formulas](#) section of [XT] **xtfrontier**, estimates for u_{it} can be obtained from the mean or the mode of the conditional distribution $f(u|\epsilon)$.

$$E(u_{it} | \epsilon_{it}) = \tilde{\mu}_i + \tilde{\sigma}_i \left\{ \frac{\phi(-\tilde{\mu}_i/\tilde{\sigma}_i)}{1 - \Phi(-\tilde{\mu}_i/\tilde{\sigma}_i)} \right\}$$

$$M(u_{it} | \epsilon_{it}) = \begin{cases} -\tilde{\mu}_i, & \text{if } \tilde{\mu}_i \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

where

$$\tilde{\mu}_i = \frac{\mu\sigma_v^2 - s \sum_{t=1}^{T_i} \eta_{it}\epsilon_{it}\sigma_u^2}{\sigma_v^2 + \sum_{t=1}^{T_i} \eta_{it}^2\sigma_u^2}$$

$$\tilde{\sigma}_i^2 = \frac{\sigma_v^2\sigma_u^2}{\sigma_v^2 + \sum_{t=1}^{T_i} \eta_{it}^2\sigma_u^2}$$

These estimates can be obtained from `predict newvar, u` and `predict newvar, m`, respectively, and are calculated by plugging in the estimated parameters.

`predict newvar, te` produces estimates of the technical-efficiency term. These estimates are obtained from

$$E\{\exp(-su_{it}) | \epsilon_{it}\} = \left[\frac{1 - \Phi\{s\eta_{it}\tilde{\sigma}_i - (\tilde{\mu}_i/\tilde{\sigma}_i)\}}{1 - \Phi(-\tilde{\mu}_i/\tilde{\sigma}_i)} \right] \exp\left(-s\eta_{it}\tilde{\mu}_i + \frac{1}{2}\eta_{it}^2\tilde{\sigma}_i^2\right)$$

Replacing $\eta_{it} = 1$ and $\eta = 0$ in these formulas produces the formulas for the time-invariant models.

Also see

[XT] **xtfrontier** — Stochastic frontier models for panel data

[U] **20 Estimation and postestimation commands**

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtgee depvar [indepvars] [if] [in] [weight] [, options]
```

<i>options</i>	Description
Model	
<u>f</u> amily(<i>family</i>)	distribution of <i>depvar</i>
<u>l</u> ink(<i>link</i>)	link function
Model 2	
<u>e</u> xposure(<i>varname</i>)	include ln(<i>varname</i>) in model with coefficient constrained to 1
<u>o</u> ffset(<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>n</u> oconstant	suppress constant term
<u>a</u> sis	retain perfect predictor variables
<u>f</u> orce	estimate even if observations unequally spaced in time
Correlation	
<u>c</u> orr(<i>correlation</i>)	within-group correlation structure
SE/Robust	
<u>v</u> ce(<i>vcetype</i>)	<i>vcetype</i> may be <u>c</u> onventional, <u>r</u> obust, <u>b</u> ootstrap, or <u>j</u> ackknife
<u>n</u> mp	use divisor $N - P$ instead of the default N
<u>r</u> gf	multiply the robust variance estimate by $(N - 1)/(N - P)$
<u>s</u> cale(<i>parm</i>)	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
Reporting	
<u>l</u> evel(#)	set confidence level; default is level(95)
<u>e</u> form	report exponentiated coefficients
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<i>optimize_options</i>	control the optimization process; seldom used
<u>n</u> odisplay	suppress display of header and coefficients
<u>c</u> oeflegend	display legend instead of statistics

A panel variable must be specified. Correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

`indepvars` may contain factor variables; see [U] [11.4.3 Factor variables](#).

`depvar` and `indepvars` may contain time-series operators; see [U] [11.4 varlists](#).

`by`, `mfp`, `mi` estimate, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#).

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi` estimate prefix; see [MI] [mi estimate](#).

`weights`, `fweights`, and `pweights` are allowed; see [U] [11.1.6 weight](#). Weights must be constant within panel.

`nodisplay` and `coeflegend` do not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

<i>family</i>	Description
<code>gaussian</code>	Gaussian (normal); <code>family(normal)</code> is a synonym
<code>igaussian</code>	inverse Gaussian
<code>binomial</code> [<code>#</code> <i>varname</i>]	Bernoulli/binomial
<code>poisson</code>	Poisson
<code>nbinomial</code> [<code>#</code>]	negative binomial
<code>gamma</code>	gamma
<hr/>	
<i>link</i>	Link function/definition
<code>identity</code>	identity; $y = y$
<code>log</code>	log; $\ln(y)$
<code>logit</code>	logit; $\ln\{y/(1 - y)\}$, natural log of the odds
<code>probit</code>	probit; $\Phi^{-1}(y)$, where $\Phi(\cdot)$ is the normal cumulative distribution
<code>cloglog</code>	cloglog; $\ln\{-\ln(1 - y)\}$
<code>power</code> [<code>#</code>]	power; y^k with $k = \#$; $\# = 1$ if not specified
<code>opower</code> [<code>#</code>]	odds power; $[\{y/(1 - y)\}^k - 1]/k$ with $k = \#$; $\# = 1$ if not specified
<code>nbinomial</code>	negative binomial; $\ln\{y/(y + \alpha)\}$
<code>reciprocal</code>	reciprocal; $1/y$
<hr/>	
<i>correlation</i>	Description
<code>exchangeable</code>	exchangeable
<code>independent</code>	independent
<code>unstructured</code>	unstructured
<code>fixed matname</code>	user-specified
<code>ar #</code>	autoregressive of order <code>#</code>
<code>stationary #</code>	stationary of order <code>#</code>
<code>nonstationary #</code>	nonstationary of order <code>#</code>

Menu

Statistics > Longitudinal/panel data > Generalized estimating equations (GEE) > Generalized estimating equations (GEE)

Description

`xtgee` fits population-averaged panel-data models. In particular, `xtgee` fits generalized linear models and allows you to specify the within-group correlation structure for the panels.

See [\[R\] logistic](#) and [\[R\] regress](#) for lists of related estimation commands.

Options

Model

`family(family)` specifies the distribution of *depvar*; `family(gaussian)` is the default.

`link(link)` specifies the link function; the default is the canonical link for the `family()` specified (except for `family(nbinomial)`).

Model 2

`exposure(varname)` and `offset(varname)` are different ways of specifying the same thing. `exposure()` specifies a variable that reflects the amount of exposure over which the *depvar* events were observed for each observation; `ln(varname)` with coefficient constrained to be 1 is entered into the regression equation. `offset()` specifies a variable that is to be entered directly into the log-link function with its coefficient constrained to be 1; thus, exposure is assumed to be e^{varname} . If you were fitting a Poisson regression model, `family(poisson) link(log)`, for instance, you would account for exposure time by specifying `offset()` containing the log of exposure time.

`noconstant` specifies that the linear predictor has no intercept term, thus forcing it through the origin on the scale defined by the link function.

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [\[R\] probit](#). This option is only allowed with option `family(binomial)` with a denominator of 1.

`force` specifies that estimation be forced even though the time variable is not equally spaced. This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

Correlation

`corr(correlation)` specifies the within-group correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

SE/Robust

`vce(vctype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`vce(robust)` specifies that the Huber/White/sandwich estimator of variance is to be used in place of the default conventional variance estimator (see [Methods and formulas](#) below). Use of this option causes `xtgee` to produce valid standard errors even if the correlations within group are not as hypothesized by the specified correlation structure. Under a noncanonical link, it does, however, require that the model correctly specifies the mean. The resulting standard errors are thus labeled “semirobust” instead of “robust” in this case. Although there is no `vce(cluster clustvar)` option, results are as if this option were included and you specified clustering on the panel variable.

`nmp`; see [XT] [vce_options](#).

`rgf` specifies that the robust variance estimate is multiplied by $(N - 1)/(N - P)$, where N is the total number of observations and P is the number of coefficients estimated. This option can be used only with `family(gaussian)` when `vce(robust)` is either specified or implied by the use of `pweights`. Using this option implies that the robust variance estimate is not invariant to the scale of any weights used.

`scale(x2|dev|phi|#)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`eform` displays the exponentiated coefficients and corresponding standard errors and confidence intervals as described in [R] [maximize](#). For `family(binomial) link(logit)` (that is, logistic regression), exponentiation results in odds ratios; for `family(poisson) link(log)` (that is, Poisson regression), exponentiated coefficients are incidence-rate ratios.

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no!stretch`; see [R] [estimation options](#).

Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following options are available with `xtgee` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses display of the header and coefficients.

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

For a thorough introduction to GEE in the estimation of GLM, see [Hardin and Hilbe \(2013\)](#). More information on linear models is presented in [Nelder and Wedderburn \(1972\)](#). Finally, there have been several illuminating articles on various applications of GEE in [Zeger, Liang, and Albert \(1988\)](#); [Zeger and Liang \(1986\)](#), and [Liang \(1987\)](#). [Pendergast et al. \(1996\)](#) surveys the current methods for analyzing clustered data in regard to binary response data. Our implementation follows that of [Liang and Zeger \(1986\)](#).

`xtgee` fits generalized linear models of y_{it} with covariates \mathbf{x}_{it}

$$g\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim F \text{ with parameters } \theta_{it}$$

for $i = 1, \dots, m$ and $t = 1, \dots, n_i$, where there are n_i observations for each group identifier i . $g(\cdot)$ is called the link function, and F is the distributional family. Substituting various definitions for $g(\cdot)$ and F results in a wide array of models. For instance, if y_{it} is distributed Gaussian (normal) and $g(\cdot)$ is the identity function, we have

$$E(y_{it}) = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim N(\cdot)$$

yielding linear regression, random-effects regression, or other regression-related models, depending on what we assume for the correlation structure.

If $g(\cdot)$ is the logit function and y_{it} is distributed Bernoulli (binomial), we have

$$\text{logit}\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim \text{Bernoulli}$$

or logistic regression. If $g(\cdot)$ is the natural log function and y_{it} is distributed Poisson, we have

$$\ln\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim \text{Poisson}$$

or Poisson regression, also known as the log-linear model. Other combinations are possible.

You specify the link function with the `link()` option, the distributional family with `family()`, and the assumed within-group correlation structure with `corr()`.

The binomial distribution can be specified as case 1 `family(binomial)`, case 2 `family(binomial #)`, or case 3 `family(binomial varname)`. In case 2, `#` is the value of the binomial denominator N , the number of trials. Specifying `family(binomial 1)` is the same as specifying `family(binomial)`; both mean that y has the Bernoulli distribution with values 0 and 1 only. In case 3, `varname` is the variable containing the binomial denominator, thus allowing the number of trials to vary across observations.

The negative binomial distribution must be specified as `family(nbinomial #)`, where `#` denotes the value of the parameter α in the negative binomial distribution. The results will be conditional on this value.

You do not have to specify both `family()` and `link()`; the default `link()` is the canonical link for the specified `family()` (excluding `family(nbinomial)`):

Family	Default link
<code>family(binomial)</code>	<code>link(logit)</code>
<code>family(gamma)</code>	<code>link(reciprocal)</code>
<code>family(gaussian)</code>	<code>link(identity)</code>
<code>family(igaussian)</code>	<code>link(power -2)</code>
<code>family(nbinomial)</code>	<code>link(log)</code>
<code>family(poisson)</code>	<code>link(log)</code>

The canonical link for the negative binomial family is obtained by specifying `link(nbinomial)`. If you specify both `family()` and `link()`, not all combinations make sense. You may choose among the following combinations:

	Gaussian	Inverse Gaussian	Binomial	Poisson	Negative Binomial	Gamma
Identity	x	x	x	x	x	x
Log	x	x	x	x	x	x
Logit			x			
Probit			x			
C. log-log			x			
Power	x	x	x	x	x	x
Odds Power			x			
Neg. binom.					x	
Reciprocal	x		x	x		x

You specify the assumed within-group correlation structure with the `corr()` option. For example, call **R** the working correlation matrix for modeling the within-group correlation, a square $\max\{n_i\} \times \max\{n_i\}$ matrix. `corr()` specifies the structure of **R**. Let $\mathbf{R}_{t,s}$ denote the t, s element.

The `independent` structure is defined as

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ 0 & \text{otherwise} \end{cases}$$

The `corr(exchangeable)` structure (corresponding to equal-correlation models) is defined as

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho & \text{otherwise} \end{cases}$$

The `corr(ar g)` structure is defined as the usual correlation matrix for an AR(g) model. This is sometimes called multiplicative correlation. For example, an AR(1) model is given by

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho^{|t-s|} & \text{otherwise} \end{cases}$$

The `corr(stationary g)` structure is a stationary(g) model. For example, a stationary(1) model is given by

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho & \text{if } |t - s| = 1 \\ 0 & \text{otherwise} \end{cases}$$

The `corr(nonstationary g)` structure is a nonstationary(g) model that imposes only the constraints that the elements of the working correlation matrix along the diagonal be 1 and the elements outside the g th band be zero,

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho_{ts} & \text{if } 0 < |t - s| \leq g, \rho_{ts} = \rho_{st} \\ 0 & \text{otherwise} \end{cases}$$

`corr(unstructured)` imposes only the constraint that the diagonal elements of the working correlation matrix be 1.

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho_{ts} & \text{otherwise, } \rho_{ts} = \rho_{st} \end{cases}$$

The `corr(fixed matname)` specification is taken from the user-supplied matrix, such that

$$\mathbf{R} = \text{matname}$$

Here the correlations are not estimated from the data. The user-supplied matrix must be a valid correlation matrix with 1s on the diagonal.

Full formulas for all the correlation structures are provided in the [Methods and formulas](#) below.

□ Technical note

Some `family()`, `link()`, and `corr()` combinations result in models already fit by Stata:

<code>family()</code>	<code>link()</code>	<code>corr()</code>	Other Stata estimation command
gaussian	identity	independent	<code>regress</code>
gaussian	identity	exchangeable	<code>xtreg, re</code>
gaussian	identity	exchangeable	<code>xtreg, pa</code>
binomial	cloglog	independent	<code>cloglog</code> (see note 1)
binomial	cloglog	exchangeable	<code>xtcloglog, pa</code>
binomial	logit	independent	<code>logit</code> or <code>logistic</code>
binomial	logit	exchangeable	<code>xtlogit, pa</code>
binomial	probit	independent	<code>probit</code> (see note 2)
binomial	probit	exchangeable	<code>xtprobit, pa</code>
nbbinomial	log	independent	<code>nbreg</code> (see note 3)
poisson	log	independent	<code>poisson</code>
poisson	log	exchangeable	<code>xtpoisson, pa</code>
gamma	log	independent	<code>streg, dist(exp) nohr</code> (see note 4)
<i>family</i>	<i>link</i>	independent	<code>glm, irls</code> (see note 5)

Notes:

1. For cloglog estimation, `xtgee` with `corr(independent)` and `cloglog` (see [\[R\] cloglog](#)) will produce the same coefficients, but the standard errors will be only asymptotically equivalent because `cloglog` is not the canonical link for the binomial family.
2. For probit estimation, `xtgee` with `corr(independent)` and `probit` will produce the same coefficients, but the standard errors will be only asymptotically equivalent because `probit` is not the canonical link for the binomial family. If the binomial denominator is not 1, the equivalent maximum-likelihood command is `bprobit`; see [\[R\] probit](#) and [\[R\] glogit](#).
3. Fitting a negative binomial model by using `xtgee` (or using `glm`) will yield results conditional on the specified value of α . The `nbreg` command, however, estimates that parameter and provides unconditional estimates; see [\[R\] nbreg](#).
4. `xtgee` with `corr(independent)` can be used to fit exponential regressions, but this requires specifying `scale(1)`. As with `probit`, the `xtgee`-reported standard errors will be only asymptotically equivalent to those produced by `streg, dist(exp) nohr` (see [\[ST\] streg](#)) because `log` is not the canonical link for the gamma family. `xtgee` cannot be used to fit exponential regressions on censored data.

Using the `independent` correlation structure, the `xtgee` command will fit the same model fit with the `glm, irls` command if the family–link combination is the same.

5. If the `xtgee` command is equivalent to another command, using `corr(independent)` and the `vce(robust)` option with `xtgee` corresponds to using the `vce(cluster clustvar)` option in the equivalent command, where *clustvar* corresponds to the panel variable. □

`xtgee` is a generalization of the `glm`, `irls` command and gives the same output when the same family and link are specified together with an independent correlation structure. What makes `xtgee` useful is

- the number of statistical models that it generalizes for use with panel data, many of which are not otherwise available in Stata;
- the richer correlation structure `xtgee` allows, even when models are available through other `xt` commands; and
- the availability of robust standard errors (see [U] 20.21 Obtaining robust variance estimates), even when the model and correlation structure are available through other `xt` commands.

In the following examples, we illustrate the relationships of `xtgee` with other Stata estimation commands. Remember that, although `xtgee` generalizes many other commands, the computational algorithm is different; therefore, the answers you obtain will not be identical. The dataset we are using is a subset of the `nlswork` data (see [XT] `xt`); we are looking at observations before 1980.

► Example 1

We can use `xtgee` to perform ordinary least squares by `regress`:

```
. use http://www.stata-press.com/data/r13/nlswork2
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. regress ln_w grade age c.age#c.age
```

Source	SS	df	MS	Number of obs = 16085		
Model	597.54468	3	199.18156	F(3, 16081) = 1413.68		
Residual	2265.74584	16081	.14089583	Prob > F = 0.0000		
				R-squared = 0.2087		
				Adj R-squared = 0.2085		
Total	2863.29052	16084	.178021047	Root MSE = .37536		

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	.0724483	.0014229	50.91	0.000	.0696592	.0752374
age	.1064874	.0083644	12.73	0.000	.0900922	.1228825
c.age#c.age	-.0016931	.0001655	-10.23	0.000	-.0020174	-.0013688
_cons	-.8681487	.1024896	-8.47	0.000	-1.06904	-.6672577


```
. xtgee ln_w grade age c.age#c.age, corr(indep) nmp
Iteration 1: tolerance = 1.285e-12

GEE population-averaged model
Group variable:          idcode      Number of obs      =      16085
Link:                   identity      Number of groups   =      3913
Family:                 Gaussian      Obs per group: min =        1
Correlation:            independent      avg =        4.1
                                      max =        9
                                      Wald chi2(3)      =      4241.04
Scale parameter:        .1408958      Prob > chi2        =      0.0000
Pearson chi2(16081):    2265.75      Deviance           =      2265.75
Dispersion (Pearson):   .1408958      Dispersion         =      .1408958
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0724483	.0014229	50.91	0.000	.0696594	.0752372
age	.1064874	.0083644	12.73	0.000	.0900935	.1228812
c.age#c.age	-.0016931	.0001655	-10.23	0.000	-.0020174	-.0013688
_cons	-.8681487	.1024896	-8.47	0.000	-1.069025	-.6672728

When `nmp` is specified, the coefficients and the standard errors produced by the estimators are the same. Moreover, the scale parameter estimate from the `xtgee` command equals the MSE calculation from `regress`; both are estimates of the variance of the residuals.



► Example 2

The identity link and Gaussian family produce regression-type models. With the independent correlation structure, we reproduce ordinary least squares. With the exchangeable correlation structure, we produce an equal-correlation linear regression estimator.

`xtgee, fam(gauss) link(ident) corr(exch)` is asymptotically equivalent to the weighted-GLS estimator provided by `xtreg, re` and to the full maximum-likelihood estimator provided by `xtreg, mle`. In balanced data, `xtgee, fam(gauss) link(ident) corr(exch)` and `xtreg, mle` produce the same results. With unbalanced data, the results are close but differ because the two estimators handle unbalanced data differently. For both balanced and unbalanced data, the results produced by `xtgee, fam(gauss) link(ident) corr(exch)` and `xtreg, mle` differ from those produced by `xtreg, re`. Below we demonstrate the use of the three estimators with unbalanced data. We begin with `xtgee`; show the maximum likelihood estimator `xtreg, mle`; show the GLS estimator `xtreg, re`; and finally show `xtgee` with the `vce(robust)` option.


```
. xtgee ln_w grade age c.age#c.age, nolog
GEE population-averaged model
Group variable:          idcode
Link:                    identity
Family:                  Gaussian
Correlation:              exchangeable
Scale parameter:         .1416586

Number of obs      =    16085
Number of groups   =     3913
Obs per group: min =         1
                  avg  =        4.1
                  max  =         9
Wald chi2(3)       =    2918.26
Prob > chi2        =     0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0717731	.00211	34.02	0.000	.0676377	.0759086
age	.1077645	.006885	15.65	0.000	.0942701	.1212589
c.age#c.age	-.0016381	.0001362	-12.03	0.000	-.001905	-.0013712
_cons	-.9480449	.0869277	-10.91	0.000	-1.11842	-.7776698

```
. xtreg ln_w grade age c.age#c.age, mle
Fitting constant-only model:
Iteration 0:  log likelihood = -6035.2751
Iteration 1:  log likelihood = -5870.6718
Iteration 2:  log likelihood = -5858.9478
Iteration 3:  log likelihood = -5858.8244
Iteration 4:  log likelihood = -5858.8244
Fitting full model:
Iteration 0:  log likelihood = -4591.9241
Iteration 1:  log likelihood = -4562.4406
Iteration 2:  log likelihood = -4562.3526
Iteration 3:  log likelihood = -4562.3525
Random-effects ML regression
Group variable: idcode
Random effects u_i ~ Gaussian

Number of obs      =    16085
Number of groups   =     3913
Obs per group: min =         1
                  avg  =        4.1
                  max  =         9
LR chi2(3)         =    2592.94
Prob > chi2        =     0.0000
Log likelihood     = -4562.3525
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0717747	.002142	33.51	0.000	.0675765	.075973
age	.1077899	.0068266	15.79	0.000	.0944101	.1211697
c.age#c.age	-.0016364	.000135	-12.12	0.000	-.0019011	-.0013718
_cons	-.9500833	.086384	-11.00	0.000	-1.119393	-.7807737
/sigma_u	.2689639	.0040854			.2610748	.2770915
/sigma_e	.2669944	.0017113			.2636613	.2703696
rho	.5036748	.0086449			.4867329	.52061

Likelihood-ratio test of sigma_u=0: chibar2(01)= 4996.22 Prob>=chibar2 = 0.000


```
. xtreg ln_w grade age c.age#c.age, re
```

```
Random-effects GLS regression           Number of obs   =   16085
Group variable: idcode                  Number of groups =   3913
R-sq:  within = 0.0983                  Obs per group: min =    1
      between = 0.2946                      avg =    4.1
      overall  = 0.2076                      max =    9
                                           Wald chi2(3)     =  2875.02
                                           Prob > chi2      =   0.0000

corr(u_i, X)  = 0 (assumed)
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0717757	.0021666	33.13	0.000	.0675294	.0760221
age	.1078042	.0068125	15.82	0.000	.0944519	.1211566
c.age#c.age	-.0016355	.0001347	-12.14	0.000	-.0018996	-.0013714
_cons	-.9512118	.0863139	-11.02	0.000	-1.120384	-.7820397
sigma_u	.27383747					
sigma_e	.26624266					
rho	.51405959	(fraction of variance due to u_i)				

```
. xtgee ln_w grade age c.age#c.age, vce(robust) nolog
```

```
GEE population-averaged model           Number of obs   =   16085
Group variable:                          idcode          Number of groups =   3913
Link:                                    identity           Obs per group: min =    1
Family:                                  Gaussian              avg =    4.1
Correlation:                             exchangeable       max =    9
                                           Wald chi2(3)     =  2031.28
Scale parameter:                         .1416586         Prob > chi2      =   0.0000
                                           (Std. Err. adjusted for clustering on idcode)
```

ln_wage	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0717731	.0023341	30.75	0.000	.0671983	.0763479
age	.1077645	.0098097	10.99	0.000	.0885379	.1269911
c.age#c.age	-.0016381	.0001964	-8.34	0.000	-.002023	-.0012532
_cons	-.9480449	.1195009	-7.93	0.000	-1.182262	-.7138274

In [R] [regress](#), `regress`, `vce(cluster clustvar)` may produce inefficient coefficient estimates with valid standard errors for random-effects models. These standard errors are robust to model misspecification. The `vce(robust)` option of `xtgee`, on the other hand, requires that the model correctly specify the mean and the link function when the noncanonical link is used.

Stored results

`xtgee` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(df_pear)</code>	degrees of freedom for Pearson χ^2
<code>e(chi2_dev)</code>	χ^2 test of deviance
<code>e(chi2_dis)</code>	χ^2 test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	pa
<code>e(family)</code>	distribution family
<code>e(link)</code>	link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	x2, dev, phi, or #, scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	nmp, if specified
<code>e(properties)</code>	b V
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by margins
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

Methods and formulas are presented under the following headings:

[Introduction](#)
[Calculating GEE for GLM](#)
[Correlation structures](#)
[Nonstationary and unstructured](#)

Introduction

xtgee fits generalized linear models for panel data with the GEE approach described in [Liang and Zeger \(1986\)](#). A related method, referred to as GEE2, is described in [Zhao and Prentice \(1990\)](#) and [Prentice and Zhao \(1991\)](#). The GEE2 method attempts to gain efficiency in the estimation of β by specifying a parametric model for α and then assumes that the models for both the mean and dependency parameters are correct. Thus there is a tradeoff in robustness for efficiency. The preliminary work of [Liang, Zeger, and Qaqish \(1992\)](#), however, indicates that there is little efficiency gained with this alternative approach.

In the GLM approach (see [McCullagh and Nelder \[1989\]](#)), we assume that

$$\begin{aligned} h(\mu_{i,j}) &= x_{i,j}^T \beta \\ \text{Var}(y_{i,j}) &= g(\mu_{i,j}) \phi \\ \mu_i &= E(\mathbf{y}_i) = \{h^{-1}(x_{i,1}^T \beta), \dots, h^{-1}(x_{i,n_i}^T \beta)\}^T \\ \mathbf{A}_i &= \text{diag}\{g(\mu_{i,1}), \dots, g(\mu_{i,n_i})\} \\ \text{Cov}(\mathbf{y}_i) &= \phi \mathbf{A}_i \quad \text{for independent observations.} \end{aligned}$$

In the absence of a convenient likelihood function with which to work, we can rely on a multivariate analog of the quasiscore function introduced by [Wedderburn \(1974\)](#):

$$\mathbf{S}_\beta(\beta, \alpha) = \sum_{i=1}^m \left(\frac{\partial \mu_i}{\partial \beta} \right)^T \text{Var}(\mathbf{y}_i)^{-1} (\mathbf{y}_i - \mu_i) = 0$$

We can solve for correlation parameters α by simultaneously solving

$$\mathbf{S}_\alpha(\beta, \alpha) = \sum_{i=1}^m \left(\frac{\partial \eta_i}{\partial \alpha} \right)^T \mathbf{H}_i^{-1} (\mathbf{W}_i - \eta_i) = 0$$

In the GEE approach to GLM, we let $\mathbf{R}_i(\alpha)$ be a “working” correlation matrix depending on the parameters in α (see the [Correlation structures](#) section for the number of parameters), and we estimate β by solving the GEE,

$$\mathbf{U}(\beta) = \sum_{i=1}^m \left(\frac{\partial \mu_i}{\partial \beta} \right)^T \mathbf{V}_i^{-1}(\alpha) (\mathbf{y}_i - \mu_i) = 0$$

where $\mathbf{V}_i(\alpha) = \mathbf{A}_i^{1/2} \mathbf{R}_i(\alpha) \mathbf{A}_i^{1/2}$

To solve this equation, we need only a crude approximation of the variance matrix, which we can obtain from a Taylor series expansion, where

$$\begin{aligned}\text{Cov}(\mathbf{y}_i) &= \mathbf{L}_i \mathbf{Z}_i \mathbf{D}_i \mathbf{Z}_i^T \mathbf{L}_i + \phi \mathbf{A}_i = \tilde{\mathbf{V}}_i \\ \mathbf{L}_i &= \text{diag}\{\partial h^{-1}(u)/\partial u, u = x_{i,j}^T \beta, j = 1, \dots, n_i\}\end{aligned}$$

which allows that

$$\begin{aligned}\hat{\mathbf{D}}_i &\approx (\mathbf{Z}_i^T \mathbf{Z}_i)^{-1} \mathbf{Z}_i \hat{\mathbf{L}}_i^{-1} \left\{ (\mathbf{y}_i - \hat{\boldsymbol{\mu}}_i)(\mathbf{y}_i - \hat{\boldsymbol{\mu}}_i)^T - \hat{\phi} \hat{\mathbf{A}}_i \right\} \hat{\mathbf{L}}_i^{-1} \mathbf{Z}_i^T (\mathbf{Z}_i^T \mathbf{Z}_i)^{-1} \\ \hat{\phi} &= \sum_{i=1}^m \sum_{j=1}^{n_i} \frac{(y_{i,j} - \hat{\mu}_{i,j})^2 - (\hat{\mathbf{L}}_{i,j})^2 \mathbf{Z}_{i,j}^T \hat{\mathbf{D}}_i \mathbf{Z}_{i,j}}{g(\hat{\mu}_{i,j})}\end{aligned}$$

Calculating GEE for GLM

Using the notation from [Liang and Zeger \(1986\)](#), let $\mathbf{y}_i = (y_{i,1}, \dots, y_{i,n_i})^T$ be the $n_i \times 1$ vector of outcome values, and let $\mathbf{X}_i = (x_{i,1}, \dots, x_{i,n_i})^T$ be the $n_i \times p$ matrix of covariate values for the i th subject $i = 1, \dots, m$. We assume that the marginal density for $y_{i,j}$ may be written in exponential family notation as

$$f(y_{i,j}) = \exp \{ \{ y_{i,j} \theta_{i,j} - a(\theta_{i,j}) + b(y_{i,j}) \} \phi \}$$

where $\theta_{i,j} = h(\eta_{i,j})$, $\eta_{i,j} = x_{i,j}^T \beta$. Under this formulation, the first two moments are given by

$$E(y_{i,j}) = a'(\theta_{i,j}), \quad \text{Var}(y_{i,j}) = a''(\theta_{i,j})/\phi$$

In what follows, we let $n_i = n$ without loss of generality. We define the quantities, assuming that we have an $n \times n$ working correlation matrix $\mathbf{R}(\alpha)$,

$$\begin{aligned}\boldsymbol{\Delta}_i &= \text{diag}(d\theta_{i,j}/d\eta_{i,j}) && n \times n \text{ matrix} \\ \mathbf{A}_i &= \text{diag}\{a''(\theta_{i,j})\} && n \times n \text{ matrix} \\ \mathbf{S}_i &= \mathbf{y}_i - a'(\boldsymbol{\theta}_i) && n \times 1 \text{ matrix} \\ \mathbf{D}_i &= \mathbf{A}_i \boldsymbol{\Delta}_i \mathbf{X}_i && n \times p \text{ matrix} \\ \mathbf{V}_i &= \mathbf{A}_i^{1/2} \mathbf{R}(\alpha) \mathbf{A}_i^{1/2} && n \times n \text{ matrix}\end{aligned}$$

such that the GEE becomes

$$\sum_{i=1}^m \mathbf{D}_i^T \mathbf{V}_i^{-1} \mathbf{S}_i = 0$$

We then have that

$$\hat{\boldsymbol{\beta}}_{j+1} = \hat{\boldsymbol{\beta}}_j - \left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{D}_i (\hat{\boldsymbol{\beta}}_j) \right\}^{-1} \left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{S}_i (\hat{\boldsymbol{\beta}}_j) \right\}$$

where the term

$$\left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{D}_i (\hat{\boldsymbol{\beta}}_j) \right\}^{-1}$$

is what we call the conventional variance estimate. It is used to calculate the standard errors if the `vce(robust)` option is not specified. This command supports the clustered version of the Huber/White/sandwich estimator of the variance with panels treated as clusters when `vce(robust)` is specified. See [P] [_robust](#), particularly [Maximum likelihood estimators](#) and [Methods and formulas](#). Liang and Zeger (1986) also discuss the calculation of the robust variance estimator.

Define the following:

$$\begin{aligned}\mathbf{D} &= (\mathbf{D}_1^T, \dots, \mathbf{D}_m^T) \\ \mathbf{S} &= (\mathbf{S}_1^T, \dots, \mathbf{S}_m^T)^T \\ \tilde{\mathbf{V}} &= nm \times nm \text{ block diagonal matrix with } \tilde{\mathbf{V}}_i \\ \mathbf{Z} &= \mathbf{D}\beta - \mathbf{S}\end{aligned}$$

At a given iteration, the correlation parameters α and scale parameter ϕ can be estimated from the current Pearson residuals, defined by

$$\hat{r}_{i,j} = \{y_{i,j} - a'(\hat{\theta}_{i,j})\} / \{a''(\hat{\theta}_{i,j})\}^{1/2}$$

where $\hat{\theta}_{i,j}$ depends on the current value for $\hat{\beta}$. We can then estimate ϕ by

$$\hat{\phi}^{-1} = \sum_{i=1}^m \sum_{j=1}^{n_i} \hat{r}_{i,j}^2 / (N - p)$$

As this general derivation is complicated, let's follow the derivation of the Gaussian family with the identity link (regression) to illustrate the generalization. After making appropriate substitutions, we will see a familiar updating equation. First, we rewrite the updating equation for β as

$$\hat{\beta}_{j+1} = \hat{\beta}_j - \mathbf{Z}_1^{-1} \mathbf{Z}_2$$

and then derive \mathbf{Z}_1 and \mathbf{Z}_2 .

$$\begin{aligned}\mathbf{Z}_1 &= \sum_{i=1}^m \mathbf{D}_i^T(\hat{\beta}_j) \tilde{\mathbf{V}}_i^{-1}(\hat{\beta}_j) \mathbf{D}_i(\hat{\beta}_j) = \sum_{i=1}^m \mathbf{X}_i^T \Delta_i^T \mathbf{A}_i^T \{ \mathbf{A}_i^{1/2} \mathbf{R}(\alpha) \mathbf{A}_i^{1/2} \}^{-1} \mathbf{A}_i \Delta_i \mathbf{X}_i \\ &= \sum_{i=1}^m \mathbf{X}_i^T \text{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X}\beta)} \right\} \text{diag} \{ a''(\theta_{i,j}) \} \left[\text{diag} \{ a''(\theta_{i,j}) \}^{1/2} \mathbf{R}(\alpha) \text{diag} \{ a''(\theta_{i,j}) \}^{1/2} \right]^{-1} \\ &\quad \text{diag} \{ a''(\theta_{i,j}) \} \text{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X}\beta)} \right\} \mathbf{X}_i \\ &= \sum_{i=1}^m \mathbf{X}_i^T \mathbf{II}(\mathbf{III})^{-1} \mathbf{II} \mathbf{X}_i = \sum_{i=1}^m \mathbf{X}_i^T \mathbf{X}_i = \mathbf{X}^T \mathbf{X}\end{aligned}$$

$$\begin{aligned}
\mathbf{Z}_2 &= \sum_{i=1}^m \mathbf{D}_i^T(\hat{\beta}_j) \tilde{\mathbf{V}}_i^{-1}(\hat{\beta}_j) \mathbf{S}_i(\hat{\beta}_j) = \sum_{i=1}^m \mathbf{X}_i^T \mathbf{\Delta}_i^T \mathbf{A}_i^T \{ \mathbf{A}_i^{1/2} \mathbf{R}(\alpha) \mathbf{A}_i^{1/2} \}^{-1} (\mathbf{y}_i - \mathbf{X}_i \hat{\beta}_j) \\
&= \sum_{i=1}^m \mathbf{X}_i^T \text{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X}_i \beta)} \right\} \text{diag} \{ a''(\theta_{i,j}) \} \left[\text{diag} \{ a''(\theta_{i,j}) \}^{1/2} \mathbf{R}(\alpha) \text{diag} \{ a''(\theta_{i,j}) \}^{1/2} \right]^{-1} \\
&\quad (\mathbf{y}_i - \mathbf{X}_i \hat{\beta}_j) \\
&= \sum_{i=1}^m \mathbf{X}_i^T \mathbf{\Pi}(\mathbf{III})^{-1} (\mathbf{y}_i - \mathbf{X}_i \hat{\beta}_j) = \sum_{i=1}^m \mathbf{X}_i^T (\mathbf{y}_i - \mathbf{X}_i \hat{\beta}_j) = \mathbf{X}^T \hat{s}_j
\end{aligned}$$

So, we may write the update formula as

$$\hat{\beta}_{j+1} = \hat{\beta}_j - (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \hat{s}_j$$

which is the same formula for GLS in regression.

Correlation structures

The working correlation matrix \mathbf{R} is a function of α and is more accurately written as $\mathbf{R}(\alpha)$. Depending on the assumed correlation structure, α might be

Independent	no parameters to estimate
Exchangeable	α is a scalar
Autoregressive	α is a vector
Stationary	α is a vector
Nonstationary	α is a matrix
Unstructured	α is a matrix

Also, throughout the estimation of a general unbalanced panel, it is more proper to discuss \mathbf{R}_i , which is the upper left $n_i \times n_i$ submatrix of the ultimately stored matrix in $\mathbf{e}(\mathbf{R})$, $\max\{n_i\} \times \max\{n_i\}$.

The only panels that enter into the estimation for a lag-dependent correlation structure are those with $n_i > g$ (assuming a lag of g). **xtgee** drops panels with too few observations (and mentions when it does so).

Independent

The working correlation matrix \mathbf{R} is an identity matrix.

Exchangeable

$$\alpha = \frac{\sum_{i=1}^m \left(\sum_{j=1}^{n_i} \sum_{k=1}^{n_i} \hat{r}_{i,j} \hat{r}_{i,k} - \sum_{j=1}^{n_i} \hat{r}_{i,j}^2 \right)}{\sum_{i=1}^m \{n_i(n_i - 1)\}} \bigg/ \frac{\sum_{i=1}^m \left(\sum_{j=1}^{n_i} \hat{r}_{i,j}^2 \right)}{\sum_{i=1}^m n_i}$$

and the working correlation matrix is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & s = t \\ \alpha & \text{otherwise} \end{cases}$$

Autoregressive and stationary

These two structures require g parameters to be estimated so that α is a vector of length $g + 1$ (the first element of α is 1).

$$\alpha = \sum_{i=1}^m \left(\frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i}, \frac{\sum_{j=1}^{n_i-1} \hat{r}_{i,j} \hat{r}_{i,j+1}}{n_i}, \dots, \frac{\sum_{j=1}^{n_i-g} \hat{r}_{i,j} \hat{r}_{i,j+g}}{n_i} \right) / \left(\sum_{i=1}^m \frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i} \right)$$

The working correlation matrix for the AR model is calculated as a function of Toeplitz matrices formed from the α vector; see [Newton \(1988\)](#). The working correlation matrix for the stationary model is given by

$$\mathbf{R}_{s,t} = \begin{cases} \alpha_{1,|s-t|} & \text{if } |s-t| \leq g \\ 0 & \text{otherwise} \end{cases}$$

Nonstationary and unstructured

These two correlation structures require a matrix of parameters. α is estimated (where we replace $\hat{r}_{i,j} = 0$ whenever $i > n_i$ or $j > n_i$) as

$$\alpha = \sum_{i=1}^m m \begin{pmatrix} N_{1,1}^{-1} \hat{r}_{i,1}^2 & N_{1,2}^{-1} \hat{r}_{i,1} \hat{r}_{i,2} & \cdots & N_{1,n}^{-1} \hat{r}_{i,1} \hat{r}_{i,n} \\ N_{2,1}^{-1} \hat{r}_{i,2} \hat{r}_{i,1} & N_{2,2}^{-1} \hat{r}_{i,2}^2 & \cdots & N_{2,n}^{-1} \hat{r}_{i,2} \hat{r}_{i,n} \\ \vdots & \vdots & \ddots & \vdots \\ N_{n,1}^{-1} \hat{r}_{i,n} \hat{r}_{i,1} & N_{n,2}^{-1} \hat{r}_{i,n} \hat{r}_{i,2} & \cdots & N_{n,n}^{-1} \hat{r}_{i,n}^2 \end{pmatrix} / \left(\sum_{i=1}^m \frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i} \right)$$

where $N_{p,q} = \sum_{i=1}^m I(i,p,q)$ and

$$I(i,p,q) = \begin{cases} 1 & \text{if panel } i \text{ has valid observations at times } p \text{ and } q \\ 0 & \text{otherwise} \end{cases}$$

where $N_{i,j} = \min(N_i, N_j)$, N_i = number of panels observed at time i , and $n = \max(n_1, n_2, \dots, n_m)$.

The working correlation matrix for the nonstationary model is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & \text{if } s = t \\ \alpha_{s,t} & \text{if } 0 < |s-t| \leq g \\ 0 & \text{otherwise} \end{cases}$$

The working correlation matrix for the unstructured model is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & \text{if } s = t \\ \alpha_{s,t} & \text{otherwise} \end{cases}$$

such that the unstructured model is equal to the nonstationary model at lag $g = n - 1$, where the panels are balanced with $n_i = n$ for all i .

References

- Caria, M. P., M. R. Galanti, R. Bellocco, and N. J. Horton. 2011. [The impact of different sources of body mass index assessment on smoking onset: An application of multiple-source information models.](#) *Stata Journal* 11: 386–402.
- Cui, J. 2007. [QIC program and model selection in GEE analyses.](#) *Stata Journal* 7: 209–220.
- Hardin, J. W., and J. M. Hilbe. 2013. [Generalized Estimating Equations.](#) 2nd ed. Boca Raton, FL: Chapman & Hall/CRC.
- Hosmer, D. W., Jr., S. A. Lemeshow, and R. X. Sturdivant. 2013. [Applied Logistic Regression.](#) 3rd ed. Hoboken, NJ: Wiley.
- Kleinbaum, D. G., and M. Klein. 2010. [Logistic Regression: A Self-Learning Text.](#) 3rd ed. New York: Springer.
- Liang, K.-Y. 1987. Estimating functions and approximate conditional likelihood. *Biometrika* 4: 695–702.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Liang, K.-Y., S. L. Zeger, and B. Qaqish. 1992. Multivariate regression analyses for categorical data. *Journal of the Royal Statistical Society, Series B* 54: 3–40.
- McCullagh, P., and J. A. Nelder. 1989. [Generalized Linear Models.](#) 2nd ed. London: Chapman & Hall/CRC.
- Nelder, J. A., and R. W. M. Wedderburn. 1972. Generalized linear models. *Journal of the Royal Statistical Society, Series A* 135: 370–384.
- Newton, H. J. 1988. *TIMESLAB: A Time Series Analysis Laboratory.* Belmont, CA: Wadsworth.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Prentice, R. L., and L. P. Zhao. 1991. Estimating equations for parameters in means and covariances of multivariate discrete and continuous responses. *Biometrics* 47: 825–839.
- Rabe-Hesketh, S., A. Pickles, and C. Taylor. 2000. [sg129: Generalized linear latent and mixed models.](#) *Stata Technical Bulletin* 53: 47–57. Reprinted in *Stata Technical Bulletin Reprints*, vol. 9, pp. 293–307. College Station, TX: Stata Press.
- Rabe-Hesketh, S., A. Skrondal, and A. Pickles. 2002. [Reliable estimation of generalized linear mixed models using adaptive quadrature.](#) *Stata Journal* 2: 1–21.
- Shults, J., S. J. Ratcliffe, and M. Leonard. 2007. [Improved generalized estimating equation analysis via xtqls for quasi-least squares in Stata.](#) *Stata Journal* 7: 147–166.
- Twisk, J. W. R. 2013. [Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide.](#) 2nd ed. Cambridge: Cambridge University Press.
- Wedderburn, R. W. M. 1974. Quasi-likelihood functions, generalized linear models, and the Gauss–Newton method. *Biometrika* 61: 439–447.
- Zeger, S. L., and K.-Y. Liang. 1986. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 42: 121–130.
- Zeger, S. L., K.-Y. Liang, and P. S. Albert. 1988. Models for longitudinal data: A generalized estimating equation approach. *Biometrics* 44: 1049–1060.
- Zhao, L. P., and R. L. Prentice. 1990. Correlated binary regression using a quadratic exponential model. *Biometrika* 77: 642–648.

Also see

- [XT] **xtgee postestimation** — Postestimation tools for xtgee
- [XT] **xtcloglog** — Random-effects and population-averaged cloglog models
- [XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models
- [XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models
- [XT] **xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [MI] **estimation** — Estimation commands for use with mi estimate
- [R] **glm** — Generalized linear models
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **regress** — Linear regression
- [U] **20 Estimation and postestimation commands**

Description	Syntax for predict	Menu for predict
Options for predict	Syntax for estat wcorrelation	Menu for estat
Options for estat wcorrelation	Remarks and examples	Also see

Description

The following postestimation command is of special interest after `xtgee`:

Command	Description
<code>estat wcorrelation</code>	estimated matrix of the within-group correlations

The following standard postestimation commands are also available:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ¹	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `forecast` is not appropriate with `mi` estimation results.

Special-interest postestimation commands

`estat wcorrelation` displays the estimated matrix of the within-group correlations.

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

statistic	Description
-----------	-------------

Main

<code>mu</code>	predicted value of <i>depvar</i> ; considers the <code>offset()</code> or <code>exposure()</code> ; the default
<code>rate</code>	predicted value of <i>depvar</i>
<code>pr(<i>n</i>)</code>	probability $\Pr(y_j = n)$ for <code>family(poisson) link(log)</code>
<code>pr(<i>a</i>,<i>b</i>)</code>	probability $\Pr(a \leq y_j \leq b)$ for <code>family(poisson) link(log)</code>
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

`mu`, the default, and `rate` calculate the predicted value of *depvar*. `mu` takes into account the `offset()` or `exposure()` together with the denominator if the family is binomial; `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()` or `exposure()` when you fit the `xtgee` model and you did not specify `family(binomial #)` or `family(binomial varname)`, meaning the binomial family and a denominator not equal to one.

Thus `mu` and `rate` are the same for `family(gaussian) link(identity)`.

`mu` and `rate` are not equivalent for `family(binomial pop) link(logit)`. Then `mu` would predict the number of positive outcomes and `rate` would predict the probability of a positive outcome.

`mu` and `rate` are not equivalent for `family(poisson) link(log) exposure(time)`. Then `mu` would predict the number of events given exposure time and `rate` would calculate the incidence rate—the number of events given an exposure time of 1.

`pr(n)` calculates the probability $\Pr(y_j = n)$ for `family(poisson) link(log)`, where *n* is a nonnegative integer that may be specified as a number or a variable.

`pr(a,b)` calculates the probability $\Pr(a \leq y_j \leq b)$ for `family(poisson) link(log)`, where *a* and *b* are nonnegative integers that may be specified as numbers or variables;

b missing (*b* $\geq .$) means $+\infty$;

`pr(20,.)` calculates $\Pr(y_j \geq 20)$;

`pr(20,b)` calculates $\Pr(y_j \geq 20)$ in observations for which *b* $\geq .$ and calculates $\Pr(20 \leq y_j \leq b)$ elsewhere.

`pr(.,b)` produces a syntax error. A missing value in an observation of the variable *a* causes a missing value in that observation for `pr(a,b)`.

`xb` calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

`score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j \boldsymbol{\beta}) / \partial (\mathbf{x}_j \boldsymbol{\beta})$.

`nooffset` is relevant only if you specified `offset(varname)`, `exposure(varname)`, `family(binomial #)`, or `family(binomial varname)` when you fit the model. It modifies the calculations made by `predict` so that they ignore the offset or exposure variable and the binomial denominator. Thus `predict ..., mu nooffset` produces the same results as `predict ..., rate`.

Syntax for estat wcorrelation

```
estat wcorrelation [ , compact format(%fmt) ]
```

Menu for estat

Statistics > Postestimation > Reports and statistics

Options for estat wcorrelation

`compact` specifies that only the parameters (alpha) of the estimated matrix of within-group correlations be displayed rather than the entire matrix.

`format(%fmt)` overrides the display format; see [D] [format](#).

Remarks and examples

► Example 1

`xtgee` can estimate rich correlation structures. In [example 2](#) of [XT] [xtgee](#), we fit the model

```
. use http://www.stata-press.com/data/r13/nlswork2
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. xtgee ln_w grade age c.age#c.age
(output omitted)
```


After estimation, `estat wcorrelation` reports the working correlation matrix **R**:

```
. estat wcorrelation
```

Estimated within-idcode correlation matrix R:

	c1	c2	c3	c4	c5	c6
r1	1					
r2	.4851356	1				
r3	.4851356	.4851356	1			
r4	.4851356	.4851356	.4851356	1		
r5	.4851356	.4851356	.4851356	.4851356	1	
r6	.4851356	.4851356	.4851356	.4851356	.4851356	1
r7	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
r8	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
r9	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
	c7	c8	c9			
r7	1					
r8	.4851356	1				
r9	.4851356	.4851356	1			

The equal-correlation model corresponds to an exchangeable correlation structure, meaning that the correlation of observations within person is a constant. The working correlation estimated by `xtgee` is 0.4851. (`xtreg`, `re`, by comparison, reports 0.5141; see the `xtreg` command in example 2 of [XT] `xtgee`.) We constrained the model to have this simple correlation structure. What if we relaxed the constraint? To go to the other extreme, let's place no constraints on the matrix (other than its being symmetric). We do this by specifying `correlation(unstructured)`, although we can abbreviate the option.

```
. xtgee ln_w grade age c.age#c.age, corr(unstr) nolog
```

```
GEE population-averaged model      Number of obs      =      16085
Group and time vars:               idcode year           Number of groups   =      3913
Link:                               identity              Obs per group: min =         1
Family:                             Gaussian                avg =         4.1
Correlation:                        unstructured          max =         9
                                   Wald chi2(3)         =      2405.20
Scale parameter:                    .1418513          Prob > chi2         =      0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0720684	.002151	33.50	0.000	.0678525	.0762843
age	.1008095	.0081471	12.37	0.000	.0848416	.1167775
c.age#c.age	-.0015104	.0001617	-9.34	0.000	-.0018272	-.0011936
_cons	-.8645484	.1009488	-8.56	0.000	-1.062404	-.6666923


```

. estat wcorrelation
Estimated within-idcode correlation matrix R:

```

	c1	c2	c3	c4	c5	c6
r1	1					
r2	.4354838	1				
r3	.4280248	.5597329	1			
r4	.3772342	.5012129	.5475113	1		
r5	.4031433	.5301403	.502668	.6216227	1	
r6	.3663686	.4519138	.4783186	.5685009	.7306005	1
r7	.2819915	.3605743	.3918118	.4012104	.4642561	.50219
r8	.3162028	.3445668	.4285424	.4389241	.4696792	.5222537
r9	.2148737	.3078491	.3337292	.3584013	.4865802	.4613128
	c7	c8	c9			
r7	1					
r8	.6475654	1				
r9	.5791417	.7386595	1			

This correlation matrix looks different from the previously constrained one and shows, in particular, that the serial correlation of the residuals diminishes as the lag increases, although residuals separated by small lags are more correlated than, say, AR(1) would imply.

► Example 2

In [example 1](#) of [\[XT\] xtprobit](#), we showed a random-effects model of unionization using the union data described in [\[XT\] xt](#). We performed the estimation using `xtprobit` but said that we could have used `xtgee` as well. Here we fit a population-averaged (equal correlation) model for comparison:

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtgee union age grade i.not_smsa south##c.year, family(binomial) link(probit)

Iteration 1: tolerance = .12544249
Iteration 2: tolerance = .0034686
Iteration 3: tolerance = .00017448
Iteration 4: tolerance = 8.382e-06
Iteration 5: tolerance = 3.997e-07

GEE population-averaged model
Group variable:          idcode
Link:                   probit
Family:                 binomial
Correlation:            exchangeable

Number of obs      =    26200
Number of groups   =    4434
Obs per group: min =      1
                  avg =     5.9
                  max =     12

Wald chi2(6)       =    242.57
Prob > chi2        =    0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0089699	.0053208	1.69	0.092	-.0014586	.0193985
grade	.0333174	.0062352	5.34	0.000	.0210966	.0455382
1.not_smsa	-.0715717	.027543	-2.60	0.009	-.1255551	-.0175884
1.south	-1.017368	.207931	-4.89	0.000	-1.424905	-.6098308
year	-.0062708	.0055314	-1.13	0.257	-.0171122	.0045706
south#c.year						
1	.0086294	.00258	3.34	0.001	.0035727	.013686
_cons	-.8670997	.294771	-2.94	0.003	-1.44484	-.2893592

Let's look at the correlation structure and then relax it:

```
. estat wcorrelation, format(%8.4f)
```

Estimated within-idcode correlation matrix R:

	c1	c2	c3	c4	c5	c6	c7
r1	1.0000						
r2	0.4615	1.0000					
r3	0.4615	0.4615	1.0000				
r4	0.4615	0.4615	0.4615	1.0000			
r5	0.4615	0.4615	0.4615	0.4615	1.0000		
r6	0.4615	0.4615	0.4615	0.4615	0.4615	1.0000	
r7	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	1.0000
r8	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r9	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r10	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r11	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r12	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
	c8	c9	c10	c11	c12		
r8	1.0000						
r9	0.4615	1.0000					
r10	0.4615	0.4615	1.0000				
r11	0.4615	0.4615	0.4615	1.0000			
r12	0.4615	0.4615	0.4615	0.4615	1.0000		

We estimate the fixed correlation between observations within person to be 0.4615. We have many data (an average of 5.9 observations on 4,434 women), so estimating the full correlation matrix is feasible. Let's do that and then examine the results:

```
. xtgee union age grade i.not_smsa south##c.year, family(binomial) link(probit)
> corr(unstr) nolog
```

```
GEE population-averaged model      Number of obs      =      26200
Group and time vars:               idcode year      Number of groups    =      4434
Link:                               probit           Obs per group: min =        1
Family:                             binomial          avg =        5.9
Correlation:                        unstructured      max =        12
                                   Wald chi2(6)       =      198.45
Scale parameter:                    1                Prob > chi2         =      0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0096612	.0053366	1.81	0.070	-.0007984	.0201208
grade	.0352762	.0065621	5.38	0.000	.0224148	.0481377
1.not_smsa	-.093073	.0291971	-3.19	0.001	-.1502983	-.0358478
1.south	-1.028526	.278802	-3.69	0.000	-1.574968	-.4820839
year	-.0088187	.005719	-1.54	0.123	-.0200278	.0023904
south#c.year						
1	.0089824	.0034865	2.58	0.010	.002149	.0158158
_cons	-.7306192	.316757	-2.31	0.021	-1.351451	-.109787


```
. estat wcorrelation, format(%8.4f)
Estimated within-idcode correlation matrix R:
```

	c1	c2	c3	c4	c5	c6	c7
r1	1.0000						
r2	0.6667	1.0000					
r3	0.6151	0.6523	1.0000				
r4	0.5268	0.5717	0.6101	1.0000			
r5	0.3309	0.3669	0.4005	0.4783	1.0000		
r6	0.3000	0.3706	0.4237	0.4562	0.6426	1.0000	
r7	0.2995	0.3568	0.3851	0.4279	0.4931	0.6384	1.0000
r8	0.2759	0.3021	0.3225	0.3751	0.4682	0.5597	0.7009
r9	0.2989	0.2981	0.3021	0.3806	0.4605	0.5068	0.6090
r10	0.2285	0.2597	0.2748	0.3637	0.3981	0.4909	0.5889
r11	0.2325	0.2289	0.2696	0.3246	0.3551	0.4426	0.5103
r12	0.2359	0.2351	0.2544	0.3134	0.3474	0.3822	0.4788

	c8	c9	c10	c11	c12
r8	1.0000				
r9	0.6714	1.0000			
r10	0.5973	0.6325	1.0000		
r11	0.5625	0.5756	0.5738	1.0000	
r12	0.4999	0.5412	0.5329	0.6428	1.0000

As before, we find that the correlation of residuals decreases as the lag increases, but more slowly than an AR(1) process.

➤ **Example 3**

In this example, we examine injury incidents among 20 airlines in each of 4 years. The data are fictional, and, as a matter of fact, are really from a random-effects model.

```
. use http://www.stata-press.com/data/r13/airacc
. generate lnpm = ln(pmiles)
. xtgee i_cnt inprog, family(poisson) eform offset(lnpm) nolog
```

GEE population-averaged model		Number of obs	=	80
Group variable:	airline	Number of groups	=	20
Link:	log	Obs per group: min	=	4
Family:	Poisson	avg	=	4.0
Correlation:	exchangeable	max	=	4
		Wald chi2(1)	=	5.27
Scale parameter:	1	Prob > chi2	=	0.0217

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
inprog	.9059936	.0389528	-2.30	0.022	.8327758 .9856487
_cons	.0080065	.0002912	-132.71	0.000	.0074555 .0085981
lnpm	1	(offset)			

```
. estat wcorrelation
Estimated within-airline correlation matrix R:
```

	c1	c2	c3	c4
r1	1			
r2	.4606406	1		
r3	.4606406	.4606406	1	
r4	.4606406	.4606406	.4606406	1

Now there are not really enough data here to reliably estimate the correlation without any constraints of structure, but here is what happens if we try:

```
. xtgee i_cnt inprog, family(poisson) eform offset(lnpm) corr(unstr) nolog
GEE population-averaged model      Number of obs      =      80
Group and time vars:      airline time      Number of groups   =      20
Link:                      log      Obs per group: min =      4
Family:                    Poisson      avg =      4.0
Correlation:              unstructured      max =      4
                                Wald chi2(1) =      0.36
                                Prob > chi2 =      0.5496
Scale parameter:              1
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.9791082	.0345486	-0.60	0.550	.9136826	1.049219
_cons	.0078716	.0002787	-136.82	0.000	.0073439	.0084373
lnpm	1	(offset)				

```
. estat wcorrelation
```

Estimated within-airline correlation matrix R:

	c1	c2	c3	c4
r1	1			
r2	.5700298	1		
r3	.716356	.4192126	1	
r4	.2383264	.3839863	.3521287	1

There is no sensible pattern to the correlations.

We created this dataset from a random-effects Poisson model. We reran our data-creation program and this time had it create 400 airlines rather than 20, still with 4 years of data each. Here are the equal-correlation model and estimated correlation structure:

```
. use http://www.stata-press.com/data/r13/airacc2, clear
. xtgee i_cnt inprog, family(poisson) eform offset(lnpm) nolog
GEE population-averaged model      Number of obs      =     1600
Group variable:      airline      Number of groups   =     400
Link:                      log      Obs per group: min =      4
Family:                    Poisson      avg =      4.0
Correlation:              exchangeable      max =      4
                                Wald chi2(1) =     111.80
                                Prob > chi2 =      0.0000
Scale parameter:              1
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.8915304	.0096807	-10.57	0.000	.8727571	.9107076
_cons	.0071357	.0000629	-560.57	0.000	.0070134	.0072601
lnpm	1	(offset)				

```
. estat wcorrelation
```

Estimated within-airline correlation matrix R:

	c1	c2	c3	c4
r1	1			
r2	.5291707	1		
r3	.5291707	.5291707	1	
r4	.5291707	.5291707	.5291707	1

The following estimation results assume unstructured correlation:

```
. xtgee i_cnt inprog, family(poisson) corr(unstr) eform offset(lnpm) nolog
GEE population-averaged model                Number of obs      =      1600
Group and time vars:      airline time      Number of groups   =       400
Link:                      log              Obs per group: min =        4
Family:                    Poisson          avg              =       4.0
Correlation:              unstructured      max              =        4
                                           Wald chi2(1)       =     113.43
Scale parameter:          1                Prob > chi2        =      0.0000
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.8914155	.0096208	-10.65	0.000	.8727572	.9104728
_cons	.0071402	.0000628	-561.50	0.000	.0070181	.0072645
lnpm	1	(offset)				

```
. estat wcorrelation
Estimated within-airline correlation matrix R:
```

	c1	c2	c3	c4
r1	1			
r2	.4733189	1		
r3	.5240576	.5748868	1	
r4	.5139748	.5048895	.5840707	1

The equal-correlation model estimated a fixed correlation of 0.5292, and above we have correlations ranging between 0.4733 and 0.5841 with little pattern in their structure.



Also see

- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [U] **20 Estimation and postestimation commands**

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtgls depvar [indepvars] [if] [in] [weight] [, options]
```

options	Description
Model	
<code>noconstant</code>	suppress constant term
<code>panels(iid)</code>	use i.i.d. error structure
<code>panels(heteroskedastic)</code>	use heteroskedastic but uncorrelated error structure
<code>panels(correlated)</code>	use heteroskedastic and correlated error structure
<code>corr(independent)</code>	use independent autocorrelation structure
<code>corr(ar1)</code>	use AR1 autocorrelation structure
<code>corr(psar1)</code>	use panel-specific AR1 autocorrelation structure
<code>rhotype(calc)</code>	specify method to compute autocorrelation parameter; see Options for details; seldom used
<code>igls</code>	use iterated GLS estimator instead of two-step GLS estimator
<code>force</code>	estimate even if observations unequally spaced in time
SE	
<code>nmk</code>	normalize standard error by $N - k$ instead of N
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<code>optimize_options</code>	control the optimization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified. For correlation structures other than `independent`, a time variable must be specified. A time variable must also be specified if `panels(correlated)` is specified. Use `xtset`; see [\[XT\] xtset](#). `indepvars` may contain factor variables; see [\[U\] 11.4.3 Factor variables](#). `depvar` and `indepvars` may contain time-series operators; see [\[U\] 11.4.4 Time-series varlists](#). `by` and `statsby` are allowed; see [\[U\] 11.1.10 Prefix commands](#). `aweights` are allowed; see [\[U\] 11.1.6 weight](#). `coeflegend` does not appear in the dialog box. See [\[U\] 20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Contemporaneous correlation > GLS regression with correlated disturbances

Description

xtgls fits panel-data linear models by using feasible generalized least squares. This command allows estimation in the presence of AR(1) autocorrelation within panels and cross-sectional correlation and heteroskedasticity across panels.

Options

Model

noconstant; see [\[R\] estimation options](#).

panels(*pdist*) specifies the error structure across panels.

panels(*iid*) specifies a homoskedastic error structure with no cross-sectional correlation. This is the default.

panels(*heteroskedastic*) specifies a heteroskedastic error structure with no cross-sectional correlation.

panels(*correlated*) specifies a heteroskedastic error structure with cross-sectional correlation. If **p**(*c*) is specified, you must also specify a time variable (use **xtset**). The results will be based on a generalized inverse of a singular matrix unless $T \geq m$ (the number of periods is greater than or equal to the number of panels).

corr(*corr*) specifies the assumed autocorrelation within panels.

corr(*independent*) specifies that there is no autocorrelation. This is the default.

corr(*ar1*) specifies that, within panels, there is AR(1) autocorrelation and that the coefficient of the AR(1) process is common to all the panels. If **c**(*ar1*) is specified, you must also specify a time variable (use **xtset**).

corr(*psar1*) specifies that, within panels, there is AR(1) autocorrelation and that the coefficient of the AR(1) process is specific to each panel. **psar1** stands for panel-specific AR(1). If **c**(*psar1*) is specified, a time variable must also be specified; use **xtset**.

rho(*type*(*calc*)) specifies the method to be used to calculate the autocorrelation parameter:

regress	regression using lags; the default
dw	Durbin–Watson calculation
freg	regression using leads
nagar	Nagar calculation
theil	Theil calculation
tscorr	time-series autocorrelation calculation

All the calculations are asymptotically equivalent and consistent; this is a rarely used option.

igls requests an iterated GLS estimator instead of the two-step GLS estimator for a nonautocorrelated model or instead of the three-step GLS estimator for an autocorrelated model. The iterated GLS estimator converges to the MLE for the **corr**(*independent*) models but does not for the other **corr**() models.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE

`nmk` specifies that standard errors be normalized by $N - k$, where k is the number of parameters estimated, rather than N , the number of observations. Different authors have used one or the other normalization. [Greene \(2012, 280\)](#) remarks that whether a degree-of-freedom correction improves the small-sample properties is an open question.

Reporting

`level(#)`; see [\[R\] estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] estimation options](#).

Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-7)` is the default.

`nolog` suppresses display of the iteration log.

The following option is available with `xtgls` but is not shown in the dialog box:

`coeflegend`; see [\[R\] estimation options](#).

Remarks and examples

Remarks are presented under the following headings:

Introduction

Heteroskedasticity across panels

Correlation across panels (cross-sectional correlation)

Autocorrelation within panels

Introduction

Information on GLS can be found in [Greene \(2012\)](#), [Maddala and Lahiri \(2006\)](#), [Davidson and MacKinnon \(1993\)](#), and [Judge et al. \(1985\)](#).

If you have many panels relative to periods, see [\[XT\] xtreg](#) and [\[XT\] xtgee](#). `xtgee`, in particular, provides capabilities similar to those of `xtgls` but does not allow cross-sectional correlation. On the other hand, `xtgee` allows a richer description of the correlation within panels as long as the same correlations apply to all panels. `xtgls` provides two unique features:

1. Cross-sectional correlation may be modeled (`panels(correlated)`).
2. Within panels, the AR(1) correlation coefficient may be unique (`corr(pсар1)`).

`xtgls` allows models with heteroskedasticity and no cross-sectional correlation, but, strictly speaking, `xtgee` does not. `xtgee` with the `vce(robust)` option relaxes the assumption of equal variances, at least as far as the standard error calculation is concerned.

Also, `xtgls, panels(iid) corr(independent) nmk` is equivalent to `regress`.

The `nmk` option uses $n - k$ rather than n to normalize the variance calculation.

To fit a model with autocorrelated errors (`corr(ar1)` or `corr(pсар1)`), the data must be equally spaced in time. To fit a model with cross-sectional correlation (`panels(correlated)`), panels must have the same number of observations (be balanced).

The equation from which the models are developed is given by

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \epsilon_{it}$$

where $i = 1, \dots, m$ is the number of units (or panels) and $t = 1, \dots, T_i$ is the number of observations for panel i . This model can equally be written as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_m \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_m \end{bmatrix} \boldsymbol{\beta} + \begin{bmatrix} \boldsymbol{\epsilon}_1 \\ \boldsymbol{\epsilon}_2 \\ \vdots \\ \boldsymbol{\epsilon}_m \end{bmatrix}$$

The variance matrix of the disturbance terms can be written as

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Omega} = \begin{bmatrix} \sigma_{1,1}\boldsymbol{\Omega}_{1,1} & \sigma_{1,2}\boldsymbol{\Omega}_{1,2} & \cdots & \sigma_{1,m}\boldsymbol{\Omega}_{1,m} \\ \sigma_{2,1}\boldsymbol{\Omega}_{2,1} & \sigma_{2,2}\boldsymbol{\Omega}_{2,2} & \cdots & \sigma_{2,m}\boldsymbol{\Omega}_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m,1}\boldsymbol{\Omega}_{m,1} & \sigma_{m,2}\boldsymbol{\Omega}_{m,2} & \cdots & \sigma_{m,m}\boldsymbol{\Omega}_{m,m} \end{bmatrix}$$

For the $\boldsymbol{\Omega}_{i,j}$ matrices to be parameterized to model cross-sectional correlation, they must be square (balanced panels).

In these models, we assume that the coefficient vector $\boldsymbol{\beta}$ is the same for all panels and consider a variety of models by changing the assumptions on the structure of $\boldsymbol{\Omega}$.

For the classic OLS regression model, we have

$$\begin{aligned} E[\epsilon_{i,t}] &= 0 \\ \text{Var}[\epsilon_{i,t}] &= \sigma^2 \\ \text{Cov}[\epsilon_{i,t}, \epsilon_{j,s}] &= 0 \quad \text{if } t \neq s \text{ or } i \neq j \end{aligned}$$

This amounts to assuming that Ω has the structure given by

$$\Omega = \begin{bmatrix} \sigma^2 \mathbf{I} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \sigma^2 \mathbf{I} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \sigma^2 \mathbf{I} \end{bmatrix}$$

whether or not the panels are balanced (the $\mathbf{0}$ matrices may be rectangular). The classic OLS assumptions are the default `panels(iid)` and `corr(independent)` options for this command.

Heteroskedasticity across panels

In many cross-sectional datasets, the variance for each of the panels differs. It is common to have data on countries, states, or other units that have variation of scale. The heteroskedastic model is specified by including the `panels(heteroskedastic)` option, which assumes that

$$\Omega = \begin{bmatrix} \sigma_1^2 \mathbf{I} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \sigma_2^2 \mathbf{I} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \sigma_m^2 \mathbf{I} \end{bmatrix}$$

► Example 1

Greene (2012, 1112) reprints data in a classic study of investment demand by Grunfeld and Griliches (1960). Below we allow the variances to differ for each of the five companies.

```
. use http://www.stata-press.com/data/r13/invest2
. xtgls invest market stock, panels(hetero)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels:      heteroskedastic
Correlation: no autocorrelation

Estimated covariances   =      5      Number of obs      =     100
Estimated autocorrelations =      0      Number of groups   =      5
Estimated coefficients   =      3      Time periods       =     20
                                   Wald chi2(2)         =    865.38
                                   Prob > chi2          =    0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.0949905	.007409	12.82	0.000	.0804692	.1095118
stock	.3378129	.0302254	11.18	0.000	.2785722	.3970535
_cons	-36.2537	6.124363	-5.92	0.000	-48.25723	-24.25017

Correlation across panels (cross-sectional correlation)

We may wish to assume that the error terms of panels are correlated, in addition to having different scale variances. The variance structure is specified by including the `panels(correlated)` option and is given by

$$\Omega = \begin{bmatrix} \sigma_1^2 \mathbf{I} & \sigma_{1,2} \mathbf{I} & \cdots & \sigma_{1,m} \mathbf{I} \\ \sigma_{2,1} \mathbf{I} & \sigma_2^2 \mathbf{I} & \cdots & \sigma_{2,m} \mathbf{I} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m,1} \mathbf{I} & \sigma_{m,2} \mathbf{I} & \cdots & \sigma_m^2 \mathbf{I} \end{bmatrix}$$

Because we must estimate cross-sectional correlation in this model, the panels must be balanced (and $T \geq m$ for valid results). A time variable must also be specified so that `xtgls` knows how the observations within panels are ordered. `xtset` shows us that this is true.

➤ Example 2

```
. xtset
      panel variable:  company (strongly balanced)
      time variable:  time, 1 to 20
              delta:  1 unit

. xtgls invest market stock, panels(correlated)
Cross-sectional time-series FGLS regression
Coefficients:  generalized least squares
Panels:        heteroskedastic with cross-sectional correlation
Correlation:   no autocorrelation

Estimated covariances      =          15      Number of obs      =          100
Estimated autocorrelations =           0      Number of groups   =           5
Estimated coefficients     =           3      Time periods        =          20
                                   Wald chi2(2)      =      1285.19
                                   Prob > chi2       =       0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.0961894	.0054752	17.57	0.000	.0854583	.1069206
stock	.3095321	.0179851	17.21	0.000	.2742819	.3447822
_cons	-38.36128	5.344871	-7.18	0.000	-48.83703	-27.88552

The estimated cross-sectional covariances are stored in `e(Sigma)`.

```
. matrix list e(Sigma)
symmetric e(Sigma) [5,5]
      _ee      _ee2      _ee3      _ee4      _ee5
 _ee  9410.9061
 _ee2 -168.04631   755.85077
 _ee3 -1915.9538  -4163.3434   34288.49
 _ee4 -1129.2896  -80.381742   2259.3242   633.42367
 _ee5  258.50132   4035.872  -27898.235  -1170.6801   33455.511
```


► Example 3

We can obtain the MLE results by specifying the `igls` option, which iterates the GLS estimation technique to convergence:

```
. xtgls invest market stock, panels(correlated) igls
Iteration 1: tolerance = .2127384
Iteration 2: tolerance = .22817
(output omitted)
Iteration 1046: tolerance = 1.000e-07

Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels:      heteroskedastic with cross-sectional correlation
Correlation: no autocorrelation

Estimated covariances      =          15      Number of obs      =          100
Estimated autocorrelations =           0      Number of groups   =           5
Estimated coefficients     =           3      Time periods        =          20
Log likelihood              = -515.4222      Wald chi2(2)         =       558.51
                                Prob > chi2      =       0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.023631	.004291	5.51	0.000	.0152207	.0320413
stock	.1709472	.0152526	11.21	0.000	.1410526	.2008417
_cons	-2.216508	1.958845	-1.13	0.258	-6.055774	1.622759

Here the log likelihood is reported in the header of the output.

◀

Autocorrelation within panels

The individual identity matrices along the diagonal of Ω may be replaced with more general structures to allow for serial correlation. `xtgls` allows three options so that you may assume a structure with `corr(independent)` (no autocorrelation); `corr(ar1)` (serial correlation where the correlation parameter is common for all panels); or `corr(pсар1)` (serial correlation where the correlation parameter is unique for each panel).

The restriction of a common autocorrelation parameter is reasonable when the individual correlations are nearly equal and the time series are short.

If the restriction of a common autocorrelation parameter is reasonable, this allows us to use more information in estimating the autocorrelation parameter to produce a more reasonable estimate of the regression coefficients.

When you specify `corr(ar1)` or `corr(pсар1)`, the iterated GLS estimator does not converge to the MLE.

➤ Example 4

If `corr(ar1)` is specified, each group is assumed to have errors that follow the same AR(1) process; that is, the autocorrelation parameter is the same for all groups.

```
. xtgls invest market stock, panels(hetero) corr(ar1)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels:      heteroskedastic
Correlation: common AR(1) coefficient for all panels (0.8651)
Estimated covariances      =          5      Number of obs      =       100
Estimated autocorrelations =          1      Number of groups   =         5
Estimated coefficients      =          3      Time periods       =        20
                                           Wald chi2(2)         =       119.69
                                           Prob > chi2          =        0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.0744315	.0097937	7.60	0.000	.0552362	.0936268
stock	.2874294	.0475391	6.05	0.000	.1942545	.3806043
_cons	-18.96238	17.64943	-1.07	0.283	-53.55464	15.62987



➤ Example 5

If `corr(psar1)` is specified, each group is assumed to have errors that follow a different AR(1) process.

```
. xtgls invest market stock, panels(iid) corr(psar1)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels:      homoskedastic
Correlation: panel-specific AR(1)
Estimated covariances      =          1      Number of obs      =       100
Estimated autocorrelations =          5      Number of groups   =         5
Estimated coefficients      =          3      Time periods       =        20
                                           Wald chi2(2)         =       252.93
                                           Prob > chi2          =        0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.0934343	.0097783	9.56	0.000	.0742693	.1125993
stock	.3838814	.0416775	9.21	0.000	.302195	.4655677
_cons	-10.1246	34.06675	-0.30	0.766	-76.8942	56.64499



Stored results

xtgls stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_t)</code>	number of periods
<code>e(N_miss)</code>	number of missing observations
<code>e(n_cf)</code>	number of estimated coefficients
<code>e(n_cv)</code>	number of estimated covariances
<code>e(n_cr)</code>	number of estimated correlations
<code>e(df_pear)</code>	degrees of freedom for Pearson χ^2
<code>e(chi2)</code>	χ^2
<code>e(df)</code>	degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of $e(V)$
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	xtgls
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(coefftype)</code>	estimation scheme
<code>e(corr)</code>	correlation structure
<code>e(vt)</code>	panel option
<code>e(rhotype)</code>	type of estimated correlation
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(rho)</code>	ρ
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(asbalanced)</code>	factor variables fvset as asbalanced
<code>e(asobserved)</code>	factor variables fvset as asobserved

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\widehat{\Sigma}$ matrix
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

The GLS results are given by

$$\widehat{\beta}_{\text{GLS}} = (\mathbf{X}'\widehat{\Omega}^{-1}\mathbf{X})^{-1}\mathbf{X}'\widehat{\Omega}^{-1}\mathbf{y}$$

$$\widehat{\text{Var}}(\widehat{\beta}_{\text{GLS}}) = (\mathbf{X}'\widehat{\Omega}^{-1}\mathbf{X})^{-1}$$

For all our models, the Ω matrix may be written in terms of the Kronecker product:

$$\Omega = \Sigma_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

The estimated variance matrix is obtained by substituting the estimator $\widehat{\Sigma}$ for Σ , where

$$\widehat{\Sigma}_{i,j} = \frac{\widehat{\epsilon}_i' \widehat{\epsilon}_j}{T}$$

The residuals used in estimating Σ are first obtained from OLS regression. If the estimation is iterated, residuals are obtained from the last fitted model.

Maximum likelihood estimates may be obtained by iterating the FGLS estimates to convergence for models with no autocorrelation, `corr(independent)`.

The GLS estimates and their associated standard errors are calculated using $\widehat{\Sigma}^{-1}$. As [Beck and Katz \(1995\)](#) point out, the Σ matrix is of rank at most $\min(T, m)$ when you use the `panels(correlated)` option. For the GLS results to be valid (not based on a generalized inverse), T must be at least as large as m , as you need at least as many period observations as there are panels.

[Beck and Katz \(1995\)](#) suggest using OLS parameter estimates with asymptotic standard errors that are corrected for correlation between the panels. This estimation can be performed with the `xtpcse` command; see [\[XT\] xtpcse](#).

References

- Baum, C. F. 2001. [Residual diagnostics for cross-section time series regression models](#). *Stata Journal* 1: 101–104.
- Beck, N. L., and J. N. Katz. 1995. What to do (and not to do) with time-series cross-section data. *American Political Science Review* 89: 634–647.
- Blackwell, J. L., III. 2005. [Estimation and testing of fixed-effect panel-data systems](#). *Stata Journal* 5: 202–207.
- Davidson, R., and J. G. MacKinnon. 1993. *Estimation and Inference in Econometrics*. New York: Oxford University Press.
- Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Grunfeld, Y., and Z. Griliches. 1960. Is aggregation necessarily bad? *Review of Economics and Statistics* 42: 1–13.
- Hoechle, D. 2007. [Robust standard errors for panel regressions with cross-sectional dependence](#). *Stata Journal* 7: 281–312.
- Judge, G. G., W. E. Griffiths, R. C. Hill, H. Lütkepohl, and T.-C. Lee. 1985. *The Theory and Practice of Econometrics*. 2nd ed. New York: Wiley.
- Maddala, G. S., and K. Lahiri. 2006. *Introduction to Econometrics*. 4th ed. New York: Wiley.

Also see

- [\[XT\] xtgls postestimation](#) — Postestimation tools for xtgls
- [\[XT\] xtset](#) — Declare data to be panel data
- [\[XT\] xtpcse](#) — Linear regression with panel-corrected standard errors
- [\[XT\] xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [\[XT\] xtregar](#) — Fixed- and random-effects linear models with an AR(1) disturbance
- [\[R\] regress](#) — Linear regression
- [\[TS\] newey](#) — Regression with Newey–West standard errors
- [\[TS\] prais](#) — Prais–Winsten and Cochrane–Orcutt regression
- [\[U\] 20 Estimation and postestimation commands](#)

Description

The following postestimation commands are available after `xtgls`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

* `estat ic` and `lrtest` are available only if `igls` and `corr(independent)` were specified at estimation.

Syntax for predict

```
predict [type] newvar [if] [in] [, xb stdp]
```

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

`xb`, the default, calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

Also see

[XT] [xtgls](#) — Fit panel-data models by using GLS

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xthtaylor depvar indepvars [if] [in] [weight] , endog(varlist) [options]
```

<i>options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
* <u>endog</u> (<i>varlist</i>)	explanatory variables in <i>indepvars</i> to be treated as endogenous
<u>constant</u> (<i>varlist</i> _{ti})	independent variables that are constant within panel
<u>varying</u> (<i>varlist</i> _{tv})	independent variables that are time varying within panel
<u>amacurdy</u>	fit model based on Amemiya and MaCurdy estimator
SE	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>conventional</u> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>small</u>	report small-sample statistics

*endog(*varlist*) is required.

A panel variable must be specified. For `xthtaylor`, `amacurdy`, a time variable must also be specified. Use `xtset`; see [\[XT\] xtset](#).

depvar, *indepvars*, and all *varlists* may contain time-series operators; see [\[U\] 11.4.4 Time-series varlists](#).

`by`, `statsby`, and `xi` are allowed; see [\[U\] 11.1.10 Prefix commands](#).

`lweights` and `fweights` are allowed unless the `amacurdy` option is specified. Weights must be constant within panel; see [\[U\] 11.1.6 weight](#).

See [\[U\] 20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Hausman-Taylor regression (RE)

Description

`xthtaylor` fits panel-data random-effects models in which some of the covariates are correlated with the unobserved individual-level random effect. The estimators, originally proposed by [Hausman and Taylor \(1981\)](#) and by [Amemiya and MaCurdy \(1986\)](#), are based on instrumental variables. By default, `xthtaylor` uses the Hausman–Taylor estimator. When the `amacurdy` option is specified, `xthtaylor` uses the Amemiya–MaCurdy estimator.

Although the estimators implemented in `xhtaylor` and `xtivreg` (see [XT] `xtivreg`) use the method of instrumental variables, each command is designed for different problems. The estimators implemented in `xtivreg` assume that a subset of the explanatory variables in the model are correlated with the idiosyncratic error ϵ_{it} . In contrast, the Hausman–Taylor and Amemiya–MaCurdy estimators that are implemented in `xhtaylor` assume that some of the explanatory variables are correlated with the individual-level random effects, u_i , but that none of the explanatory variables are correlated with the idiosyncratic error, ϵ_{it} .

Options

Model

`noconstant`; see [R] [estimation options](#).

`endog(varlist)` specifies that a subset of explanatory variables in *indepvars* be treated as endogenous variables, that is, the explanatory variables that are assumed to be correlated with the unobserved random effect. `endog()` is required.

`constant(varlistti)` specifies the subset of variables in *indepvars* that are time invariant, that is, constant within panel. By using this option, you assert not only that the variables specified in *varlist_{ti}* are time invariant but also that all other variables in *indepvars* are time varying. If this assertion is false, `xhtaylor` does not perform the estimation and will issue an error message. `xhtaylor` automatically detects which variables are time invariant and which are not. However, users may want to check their understanding of the data and specify which variables are time invariant and which are not.

`varying(varlisttv)` specifies the subset of variables in *indepvars* that are time varying. By using this option, you assert not only that the variables specified in *varlist_{tv}* are time varying but also that all other variables in *indepvars* are time invariant. If this assertion is false, `xhtaylor` does not perform the estimation and issues an error message. `xhtaylor` automatically detects which variables are time varying and which are not. However, users may want to check their understanding of the data and specify which variables are time varying and which are not.

`amacurdy` specifies that the Amemiya–MaCurdy estimator be used. This estimator uses extra instruments to gain efficiency at the cost of additional assumptions on the data-generating process. This option may be specified only for samples containing balanced panels, and weights may not be specified. The panels must also have a common initial period.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for this Hausman–Taylor model.

Reporting

`level(#)`; see [R] [estimation options](#).

`small` specifies that the p -values from the Wald tests in the output and all subsequent Wald tests obtained via `test` use t and F distributions instead of the large-sample normal and χ^2 distributions. By default, the p -values are obtained using the normal and χ^2 distributions.

Remarks and examples

If you have not read [XT] `xt`, please do so.

Consider a random-effects model of the form

$$y_{it} = \mathbf{X}_{1it}\beta_1 + \mathbf{X}_{2it}\beta_2 + \mathbf{Z}_{1i}\delta_1 + \mathbf{Z}_{2i}\delta_2 + \mu_i + \epsilon_{it}$$

where

\mathbf{X}_{1it} is a $1 \times k_1$ vector of observations on exogenous, time-varying variables assumed to be uncorrelated with μ_i and ϵ_{it} ;

\mathbf{X}_{2it} is a $1 \times k_2$ vector of observations on endogenous, time-varying variables assumed to be (possibly) correlated with μ_i but orthogonal to ϵ_{it} ;

\mathbf{Z}_{1i} is a $1 \times g_1$ vector of observations on exogenous, time-invariant variables assumed to be uncorrelated with μ_i and ϵ_{it} ;

\mathbf{Z}_{2i} is a $1 \times g_2$ vector of observations on endogenous, time-invariant variables assumed to be (possibly) correlated μ_i but orthogonal to ϵ_{it} ;

μ_i is the unobserved, panel-level random effect that is assumed to have zero mean and finite variance σ_μ^2 and to be independently and identically distributed (i.i.d.) over the panels;

ϵ_{it} is the idiosyncratic error that is assumed to have zero mean and finite variance σ_ϵ^2 and to be i.i.d. over all the observations in the data;

$\beta_1, \beta_2, \delta_1$, and δ_2 are $k_1 \times 1$, $k_2 \times 1$, $g_1 \times 1$, and $g_2 \times 1$ coefficient vectors, respectively; and $i = 1, \dots, n$, where n is the number of panels in the sample and, for each i , $t = 1, \dots, T_i$.

Because \mathbf{X}_{2it} and \mathbf{Z}_{2i} may be correlated with μ_i , the simple random-effects estimators—`xtreg, re` and `xtreg, mle`—are generally not consistent for the parameters in this model. Because the within estimator, `xtreg, fe`, removes the μ_i by mean-differencing the data before estimating β_1 and β_2 , it is consistent for these parameters. However, in the process of removing the μ_i , the within estimator also eliminates the \mathbf{Z}_{1i} and the \mathbf{Z}_{2i} . Thus it cannot estimate δ_1 nor δ_2 . The Hausman–Taylor and Amemiya–MacCurdy estimators implemented in `xhtaylor` are designed to resolve this problem.

The within estimator consistently estimates β_1 and β_2 . Using these estimates, we can obtain the within residuals, called \hat{d}_i . Intermediate, albeit consistent, estimates of δ_1 and δ_2 —called $\hat{\delta}_{1IV}$ and $\hat{\delta}_{2IV}$, respectively—are obtained by regressing the within residuals on \mathbf{Z}_{1i} and \mathbf{Z}_{2i} , using \mathbf{X}_{1it} and \mathbf{Z}_{1i} as instruments. The order condition for identification requires that the number of variables in \mathbf{X}_{1it} , k_1 , be at least as large as the number of elements in \mathbf{Z}_{2i} , g_2 and that there be sufficient correlation between the instruments and \mathbf{Z}_{2i} to avoid a weak-instrument problem.

The within estimates of β_1 and β_2 and the intermediate estimates $\hat{\delta}_{1IV}$ and $\hat{\delta}_{2IV}$ can be used to obtain sets of within and overall residuals. These two sets of residuals can be used to estimate the variance components (see [Methods and formulas](#) for details).

The estimated variance components can then be used to perform a GLS transform on each of the variables. For what follows, define the general notation \check{w}_{it} to represent the GLS transform of the variable w_{it} , \bar{w}_i to represent the within-panel mean of w_{it} , and \tilde{w}_{it} to represent the within transform of w_{it} . With this notational convention, the Hausman–Taylor (1981) estimator of the coefficients of interest can be obtained by the instrumental-variables regression

$$\check{y}_{it} = \check{\mathbf{X}}_{1it}\beta_1 + \check{\mathbf{X}}_{2it}\beta_2 + \check{\mathbf{Z}}_{1i}\delta_1 + \check{\mathbf{Z}}_{2i}\delta_2 + \check{\mu}_i + \check{\epsilon}_{it} \quad (1)$$

using $\tilde{\mathbf{X}}_{1it}$, $\tilde{\mathbf{X}}_{2it}$, $\bar{\mathbf{X}}_{1i}$, $\bar{\mathbf{X}}_{2i}$, and \mathbf{Z}_{1i} as instruments.

For the instruments to be valid, this estimator requires that $\bar{\mathbf{X}}_{1i}$ and \mathbf{Z}_{1i} be uncorrelated with the random-effect μ_i . More precisely, the instruments are valid when

$$\text{plim}_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \bar{\mathbf{X}}_{1i} \mu_i = 0$$

and

$$\text{plim}_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \mathbf{Z}_{1i} \mu_i = 0$$

Amemiya and MaCurdy (1986) place stricter requirements on the instruments that vary within panels to obtain a more efficient estimator. Specifically, Amemiya and MaCurdy (1986) assume that \mathbf{X}_{1it} is orthogonal to μ_i in every period; that is, $\text{plim}_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \mathbf{X}_{1it} \mu_i = 0$ for $t = 1, \dots, T$. With this restriction, they derive the Amemiya–MaCurdy estimator as the instrumental-variables regression of (1) using instruments $\tilde{\mathbf{X}}_{1it}$, $\tilde{\mathbf{X}}_{2it}$, \mathbf{X}_{1it}^* , and \mathbf{Z}_{1i} . The order condition for the Amemiya–MaCurdy estimator is now $Tk_1 > g_2$. **xthtaylor** uses the Amemiya–MaCurdy estimator when the **amacurdy** option is specified.

► Example 1

This example replicates the results of Baltagi and Khanti-Akom (1990, table II, column HT) using 595 observations on individuals over 1976–1982 that were extracted from the Panel Study of Income Dynamics (PSID). In the model, the log-transformed wage **lwage** is assumed to be a function of how long the person has worked for a firm, **wks**; binary variables indicating whether a person lives in a large metropolitan area or in the south, **smsa** and **south**; marital status is **ms**; years of education, **ed**; a quadratic of work experience, **exp** and **exp2**; occupation, **occ**; a binary variable indicating employment in a manufacture industry, **ind**; a binary variable indicating that wages are set by a union contract, **union**; a binary variable indicating gender, **fem**; and a binary variable indicating whether the individual is African American, **blk**.

We suspect that the time-varying variables **exp**, **exp2**, **wks**, **ms**, and **union** are all correlated with the unobserved individual random effect. We can inspect these variables to see if they exhibit sufficient within-panel variation to serve as their own instruments.


```
. use http://www.stata-press.com/data/r13/psidextract
```

```
. xtsum exp exp2 wks ms union
```

Variable		Mean	Std. Dev.	Min	Max	Observations	
exp	overall	19.85378	10.96637	1	51	N =	4165
	between		10.79018	4	48	n =	595
	within		2.00024	16.85378	22.85378	T =	7
exp2	overall	514.405	496.9962	1	2601	N =	4165
	between		489.0495	20	2308	n =	595
	within		90.44581	231.405	807.405	T =	7
wks	overall	46.81152	5.129098	5	52	N =	4165
	between		3.284016	31.57143	51.57143	n =	595
	within		3.941881	12.2401	63.66867	T =	7
ms	overall	.8144058	.3888256	0	1	N =	4165
	between		.3686109	0	1	n =	595
	within		.1245274	-.0427371	1.671549	T =	7
union	overall	.3639856	.4812023	0	1	N =	4165
	between		.4543848	0	1	n =	595
	within		.1593351	-.4931573	1.221128	T =	7

We are also going to assume that the exogenous variables `occ`, `south`, `smsa`, `ind`, `fem`, and `blk` are instruments for the endogenous, time-invariant variable `ed`. The output below indicates that although `fem` appears to be a weak instrument, the remaining instruments are probably sufficiently correlated to identify the coefficient on `ed`. (See [Baltagi and Khanti-Akom \[1990\]](#) for more discussion.)

```
. correlate fem blk occ south smsa ind ed
(obs=4165)
```

	fem	blk	occ	south	smsa	ind	ed
fem	1.0000						
blk	0.2086	1.0000					
occ	-0.0847	0.0837	1.0000				
south	0.0516	0.1218	0.0413	1.0000			
smsa	0.1044	0.1154	-0.2018	-0.1350	1.0000		
ind	-0.1778	-0.0475	0.2260	-0.0769	-0.0689	1.0000	
ed	-0.0012	-0.1196	-0.6194	-0.1216	0.1843	-0.2365	1.0000

We will assume that the correlations are strong enough and proceed with the estimation. The output below gives the Hausman–Taylor estimates for this model.


```
. xthtaylor lwage occ south smsa ind exp exp2 wks ms union fem blk ed,
> endog(exp exp2 wks ms union ed)

Hausman-Taylor estimation
Group variable: id

Number of obs      =      4165
Number of groups   =      595
Obs per group: min =         7
                  avg  =         7
                  max  =         7

Random effects u_i ~ i.i.d.

Wald chi2(12)      =    6891.87
Prob > chi2        =     0.0000
```

lwage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
TVexogenous						
occ	-.0207047	.0137809	-1.50	0.133	-.0477149	.0063055
south	.0074398	.031955	0.23	0.816	-.0551908	.0700705
smsa	-.0418334	.0189581	-2.21	0.027	-.0789906	-.0046761
ind	.0136039	.0152374	0.89	0.372	-.0162608	.0434686
TVendogenous						
exp	.1131328	.002471	45.79	0.000	.1082898	.1179758
exp2	-.0004189	.0000546	-7.67	0.000	-.0005259	-.0003119
wks	.0008374	.0005997	1.40	0.163	-.0003381	.0020129
ms	-.0298508	.01898	-1.57	0.116	-.0670508	.0073493
union	.0327714	.0149084	2.20	0.028	.0035514	.0619914
TIexogenous						
fem	-.1309236	.126659	-1.03	0.301	-.3791707	.1173234
blk	-.2857479	.1557019	-1.84	0.066	-.5909179	.0194221
TIendogenous						
ed	.137944	.0212485	6.49	0.000	.0962977	.1795902
_cons	2.912726	.2836522	10.27	0.000	2.356778	3.468674
sigma_u	.94180304					
sigma_e	.15180273					
rho	.97467788	(fraction of variance due to u_i)				

Note: TV refers to time varying; TI refers to time invariant.

The estimated σ_μ and σ_ϵ are 0.9418 and 0.1518, respectively, indicating that a large fraction of the total error variance is attributed to μ_i . The z statistics indicate that several the coefficients may not be significantly different from zero. Whereas the coefficients on the time-invariant variables `fem` and `blk` have relatively large standard errors, the standard error for the coefficient on `ed` is relatively small.

Baltagi and Khanti-Akom (1990) also present evidence that the efficiency gains of the Amemiya–MaCurdy estimator over the Hausman–Taylor estimator are small for these data. This point is especially important given the additional restrictions that the estimator places on the data-generating process. The output below replicates the Baltagi and Khanti-Akom (1990) results from column AM of table II.


```
. xthtaylor lwage occ south smsa ind exp exp2 wks ms union fem blk ed,
> endog(exp exp2 wks ms union ed) amacurdy
```

Amemiya-MaCurdy estimation

Group variable: id

Time variable: t

Random effects u_i ~ i.i.d.

Number of obs	=	4165
Number of groups	=	595
Obs per group: min	=	7
avg	=	7
max	=	7
Wald chi2(12)	=	6879.20
Prob > chi2	=	0.0000

lwage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
TVexogenous						
occ	-.0208498	.0137653	-1.51	0.130	-.0478292	.0061297
south	.0072818	.0319365	0.23	0.820	-.0553126	.0698761
smsa	-.0419507	.0189471	-2.21	0.027	-.0790864	-.0048149
ind	.0136289	.015229	0.89	0.371	-.0162194	.0434771
TVendogenous						
exp	.1129704	.0024688	45.76	0.000	.1081316	.1178093
exp2	-.0004214	.0000546	-7.72	0.000	-.0005283	-.0003145
wks	.0008381	.0005995	1.40	0.162	-.0003368	.002013
ms	-.0300894	.0189674	-1.59	0.113	-.0672649	.0070861
union	.0324752	.0148939	2.18	0.029	.0032837	.0616667
TIexogenous						
fem	-.132008	.1266039	-1.04	0.297	-.380147	.1161311
blk	-.2859004	.1554857	-1.84	0.066	-.5906468	.0188459
TIendogenous						
ed	.1372049	.0205695	6.67	0.000	.0968894	.1775205
_cons	2.927338	.2751274	10.64	0.000	2.388098	3.466578
sigma_u	.94180304					
sigma_e	.15180273					
rho	.97467788	(fraction of variance due to u_i)				

Note: TV refers to time varying; TI refers to time invariant.

□ Technical note

We mentioned earlier that insufficient correlation between an endogenous variable and the instruments can give rise to a weak-instrument problem. Suppose that we simulate data for a model of the form

$$y = 3 + 3x_{1a} + 3x_{1b} + 3x_2 + 3z_1 + 3z_2 + u_i + e_{it}$$

and purposely construct the instruments so that they exhibit little correlation with the endogenous variable z_2 .


```
. use http://www.stata-press.com/data/r13/xthtaylor1
. correlate ui z1 z2 x1a x1b x2 eit
(obs=10000)
```

	ui	z1	z2	x1a	x1b	x2	eit
ui	1.0000						
z1	0.0268	1.0000					
z2	0.8777	0.0286	1.0000				
x1a	-0.0145	0.0065	-0.0034	1.0000			
x1b	0.0026	0.0079	0.0038	-0.0030	1.0000		
x2	0.8765	0.0191	0.7671	-0.0192	0.0037	1.0000	
eit	0.0060	-0.0198	0.0123	-0.0100	-0.0138	0.0092	1.0000

In the output below, weak instruments have serious consequences on the estimates produced by `xthtaylor`. The estimate of the coefficient on `z2` is three times larger than its true value, and its standard error is rather large. Without sufficient correlation between the endogenous variable and its instruments in a given sample, there is insufficient information for identifying the parameter. Also, given the results of [Stock, Wright, and Yogo \(2002\)](#), weak instruments will cause serious size distortions in any tests performed.

```
. xthtaylor yit x1a x1b x2 z1 z2, endog(x2 z2)
```

Hausman–Taylor estimation	Number of obs	=	10000
Group variable: id	Number of groups	=	1000
	Obs per group: min	=	10
	avg	=	10
	max	=	10
Random effects u_i ~ i.i.d.	Wald chi2(5)	=	24172.91
	Prob > chi2	=	0.0000

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
TVexogenous						
x1a	2.959736	.0330233	89.63	0.000	2.895011	3.02446
x1b	2.953891	.0333051	88.69	0.000	2.888614	3.019168
TVendogenous						
x2	3.022685	.033085	91.36	0.000	2.957839	3.08753
TIexogenous						
z1	2.709179	.587031	4.62	0.000	1.55862	3.859739
TIendogenous						
z2	9.525973	8.572966	1.11	0.266	-7.276732	26.32868
_cons	2.837072	.4276595	6.63	0.000	1.998875	3.675269
sigma_u	8.729479					
sigma_e	3.1657492					
rho	.88377062	(fraction of variance due to u_i)				

Note: TV refers to time varying; TI refers to time invariant.

➤ Example 2

Now let’s consider why we might want to specify the `constant(varlistti)` option. For this example, we will use simulated data. In the output below, we fit a model over the full sample. Note the placement in the output of the coefficient on the exogenous variable `x1c`.


```
. use http://www.stata-press.com/data/r13/xthttaylor2
. xthttaylor yit x1a x1b x1c x2 z1 z2, endog(x2 z2)
```

Hausman–Taylor estimation Number of obs = 10000
Group variable: id Number of groups = 1000
 Obs per group: min = 10
 avg = 10
 max = 10

Random effects u_i ~ i.i.d. Wald chi2(6) = 10341.63
 Prob > chi2 = 0.0000

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
TVexogenous						
x1a	3.023647	.0570274	53.02	0.000	2.911875	3.135418
x1b	2.966666	.0572659	51.81	0.000	2.854427	3.078905
x1c	.2355318	.123502	1.91	0.057	-.0065276	.4775912
TVendogenous						
x2	14.17476	3.128385	4.53	0.000	8.043234	20.30628
TIexogenous						
z1	1.741709	.4280022	4.07	0.000	.9028398	2.580578
TIendogenous						
z2	7.983849	.6970903	11.45	0.000	6.617577	9.350121
_cons	2.146038	.3794179	5.66	0.000	1.402393	2.889684
sigma_u	5.6787791					
sigma_e	3.1806188					
rho	.76120931	(fraction of variance due to u_i)				

Note: TV refers to time varying; TI refers to time invariant.

Now suppose that we want to fit the model using only the first eight periods. Below, x1c now appears under the TIexogenous heading rather than the TVexogenous heading because x1c is time invariant in the subsample defined by $t < 9$.


```
. xhtaylor yit x1a x1b x1c x2 z1 z2 if t<9, endog(x2 z2)
Hausman-Taylor estimation      Number of obs      =      8000
Group variable: id           Number of groups   =      1000
                               Obs per group: min =         8
                               avg =         8
                               max =         8
Random effects u_i ~ i.i.d.   Wald chi2(6)        =    15354.87
                               Prob > chi2         =         0.0000
```

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
TVexogenous						
x1a	3.051966	.0367026	83.15	0.000	2.98003	3.123901
x1b	2.967822	.0368144	80.62	0.000	2.895667	3.039977
TVendogenous						
x2	.7361217	3.199764	0.23	0.818	-5.5353	7.007543
TIexogenous						
x1c	3.215907	.5657191	5.68	0.000	2.107118	4.324696
z1	3.347644	.5819756	5.75	0.000	2.206992	4.488295
TIendogenous						
z2	2.010578	1.143982	1.76	0.079	-.231586	4.252742
_cons	3.257004	.5295828	6.15	0.000	2.219041	4.294967
sigma_u	15.445594					
sigma_e	3.175083					
rho	.95945606	(fraction of variance due to u_i)				

Note: TV refers to time varying; TI refers to time invariant.

To prevent a variable from becoming time invariant, you can use either `constant(varlistti)` or `varying(varlisttv)`. `constant(varlistti)` specifies the subset of variables in `varlist` that are time invariant and requires the remaining variables in `varlist` to be time varying. If you specify `constant(varlistti)` and any of the variables contained in `varlistti` are time varying, or if any of the variables not contained in `varlistti` are time invariant, `xhtaylor` will not perform the estimation and will issue an error message.

```
. xhtaylor yit x1a x1b x1c x2 z1 z2 if t<9, endog(x2 z2) constant(z1 z2)
x1c not included in -constant()-.
r(198);
```

The same thing happens when you use the `varying(varlisttv)` option.



Stored results

xthttaylor stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(df_r)</code>	residual degrees of freedom (small only)
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if panels balanced; 0 otherwise
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(chi2)</code>	χ^2
<code>e(rho)</code>	ρ
<code>e(F)</code>	model F (small only)
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xthttaylor</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups, amacurdy only
<code>e(TVexogenous)</code>	exogenous time-varying variables
<code>e(TIexogenous)</code>	exogenous time-invariant variables
<code>e(TVendogenous)</code>	endogenous time-varying variables
<code>e(TIendogenous)</code>	endogenous time-invariant variables
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	Hausman–Taylor or Amemiya–MaCurdy
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

Consider an error-components model of the form

$$y_{it} = \mathbf{X}_{1it}\beta_1 + \mathbf{X}_{2it}\beta_2 + \mathbf{Z}_{1i}\delta_1 + \mathbf{Z}_{2i}\delta_2 + \mu_i + \epsilon_{it} \quad (2)$$

for $i = 1, \dots, n$ and, for each i , $t = 1, \dots, T_i$, of which T_i periods are observed; n is the number of panels in the sample. The covariates in \mathbf{X} are time varying, and the covariates in \mathbf{Z} are time invariant. Both \mathbf{X} and \mathbf{Z} are decomposed into two parts. The covariates in \mathbf{X}_1 and \mathbf{Z}_1 are assumed to be uncorrelated with μ_i and ϵ_{it} , whereas the covariates in \mathbf{X}_2 and \mathbf{Z}_2 are allowed to be correlated with μ_i but not with ϵ_{it} . Hausman and Taylor (1981) suggest an instrumental-variable estimator for this model.

For some variable w , the within transformation of w is defined as

$$\tilde{w}_{it} = w_{it} - \bar{w}_i, \quad \bar{w}_i = \frac{1}{n} \sum_{t=1}^{T_i} w_{it}$$

Because the within estimator removes \mathbf{Z} , the within transformation reduces the model to

$$\tilde{y}_{it} = \tilde{\mathbf{X}}_{1it}\beta_1 + \tilde{\mathbf{X}}_{2it}\beta_2 + \tilde{\epsilon}_{it}$$

The within estimators $\hat{\beta}_{1w}$ and $\hat{\beta}_{2w}$ are consistent for β_1 and β_2 , but they may not be efficient. Also, note that the within estimator cannot estimate δ_1 and δ_2 .

From the within estimator, we can obtain an estimate of the idiosyncratic error component, σ_ϵ^2 , as

$$\hat{\sigma}_\epsilon^2 = \frac{\text{RSS}}{N - n}$$

where RSS is the residual sum of squares from the within regression and N is the total number of observations in the sample.

Using the results of the within estimation, we can define

$$\bar{d}_{it} = \bar{y}_{it} - \bar{X}_{1it}\hat{\beta}_{1w} - \bar{X}_{2it}\hat{\beta}_{2w}$$

where \bar{y}_{it} , \bar{X}_{1it} , and \bar{X}_{2it} contain the panel level means of these variables in all observations.

Regressing \bar{d}_{it} on \mathbf{Z}_1 and \mathbf{Z}_2 , using \mathbf{X}_1 and \mathbf{Z}_1 as instruments, provides intermediate, consistent estimates of δ_1 and δ_2 , which we will call $\hat{\delta}_{1IV}$ and $\hat{\delta}_{2IV}$.

Using the within estimates, $\hat{\delta}_{1IV}$, and $\hat{\delta}_{2IV}$, we can obtain an estimate of the variance of the random effect, σ_μ^2 . First, let

$$\hat{e}_{it} = \left(y_{it} - \mathbf{X}_{1it}\hat{\beta}_{1w} - \mathbf{X}_{2it}\hat{\beta}_{2w} - \mathbf{Z}_{1it}\hat{\delta}_{1IV} - \mathbf{Z}_{2it}\hat{\delta}_{2IV} \right)$$

Then define

$$s^2 = \frac{1}{N} \sum_{i=1}^n \sum_{t=1}^{T_i} \left(\frac{1}{T_i} \sum_{t=1}^{T_i} \hat{e}_{it} \right)^2$$

[Hausman and Taylor \(1981\)](#) showed that, for balanced panels,

$$\text{plim}_{n \rightarrow \infty} s^2 = T\sigma_\mu^2 + \sigma_\epsilon^2$$

For unbalanced panels,

$$\text{plim}_{n \rightarrow \infty} s^2 = \bar{T}\sigma_\mu^2 + \sigma_\epsilon^2$$

where

$$\bar{T} = \frac{n}{\sum_{i=1}^n \frac{1}{T_i}}$$

After we plug in $\hat{\sigma}_\epsilon^2$, our consistent estimate for σ_ϵ^2 , a little algebra suggests the estimate

$$\hat{\sigma}_\mu^2 = (s^2 - \hat{\sigma}_\epsilon^2)(\bar{T})^{-1}$$

Define $\hat{\theta}_i$ as

$$\hat{\theta}_i = 1 - \left(\frac{\hat{\sigma}_\epsilon^2}{\hat{\sigma}_\epsilon^2 + T_i \hat{\sigma}_\mu^2} \right)^{\frac{1}{2}}$$

With $\hat{\theta}_i$ in hand, we can perform the standard random-effects GLS transform on each of the variables. The transform is given by

$$w_{it}^* = w_{it} - \hat{\theta}_i \bar{w}_i.$$

where \bar{w}_i is the within-panel mean.

We can then obtain the Hausman–Taylor estimates of the coefficients in (2) and the conventional VCE by fitting an instrumental-variables regression of the GLS-transformed y_{it}^* on \mathbf{X}_{it}^* and \mathbf{Z}_{it}^* , with instruments $\tilde{\mathbf{X}}_{it}$, $\bar{\mathbf{X}}_{1i}$, and \mathbf{Z}_{1i} .

We can obtain Amemiya–MaCurdy estimates of the coefficients in (2) and the conventional VCE by fitting an instrumental-variables regression of the GLS-transformed y_{it}^* on \mathbf{X}_{it}^* and \mathbf{Z}_{it}^* , using $\tilde{\mathbf{X}}_{it}$, $\tilde{\mathbf{X}}_{1it}$, and \mathbf{Z}_{1i} as instruments, where $\tilde{\mathbf{X}}_{1it} = \mathbf{X}_{1i1}, \mathbf{X}_{1i2}, \dots, \mathbf{X}_{1iT_i}$. The order condition for the Amemiya–MaCurdy estimator is $Tk_1 > g_2$, and this estimator is available only for balanced panels.

References

- Amemiya, T., and T. E. MaCurdy. 1986. Instrumental-variable estimation of an error-components model. *Econometrica* 54: 869–880.
- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Baltagi, B. H., and S. Khanti-Akom. 1990. On efficient estimation with panel data: An empirical comparison of instrumental variables estimators. *Journal of Applied Econometrics* 5: 401–406.
- Hausman, J. A., and W. E. Taylor. 1981. Panel data and unobservable individual effects. *Econometrica* 49: 1377–1398.
- Stock, J. H., J. H. Wright, and M. Yogo. 2002. A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business and Economic Statistics* 20: 518–529.

Also see

- [XT] **xthtaylor postestimation** — Postestimation tools for xthtaylor
- [XT] **xtset** — Declare data to be panel data
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [U] **20 Estimation and postestimation commands**

Description
Remarks and examples

Syntax for predict
References

Menu for predict
Also see

Options for predict

Description

The following postestimation commands are available after `xhtaylor`:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	$\mathbf{X}_{it}\hat{\boldsymbol{\beta}} + \mathbf{Z}_i\hat{\boldsymbol{\delta}}$, fitted values; the default
<code>stdp</code>	standard error of the fitted values
<code>ue</code>	$\hat{\mu}_i + \hat{\epsilon}_{it}$, the combined residual
<code>*xbu</code>	$\mathbf{X}_{it}\hat{\boldsymbol{\beta}} + \mathbf{Z}_i\hat{\boldsymbol{\delta}} + \hat{\mu}_i$, prediction including effect
<code>*u</code>	$\hat{\mu}_i$, the random-error component
<code>*e</code>	$\hat{\epsilon}_{it}$, prediction of the idiosyncratic error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction, that is, $\mathbf{X}_{it}\hat{\boldsymbol{\beta}} + \mathbf{Z}_{it}\hat{\boldsymbol{\delta}}$.

stdp calculates the standard error of the linear prediction.

ue calculates the prediction of $\hat{\mu}_i + \hat{\epsilon}_{it}$.

xbu calculates the prediction of $\mathbf{X}_{it}\hat{\boldsymbol{\beta}} + \mathbf{Z}_{it}\hat{\boldsymbol{\delta}} + \hat{\nu}_i$, the prediction including the random effect.

u calculates the prediction of $\hat{\mu}_i$, the estimated random effect.

e calculates the prediction of $\hat{\epsilon}_{it}$.

Remarks and examples

► Example 1

Continuing with [example 1](#) of [XT] [xhtaylor](#), we use `hausman` to test whether we should use the Hausman–Taylor estimator instead of the fixed-effects estimator. We follow the empirical illustration in [Baltagi \(2013, sec. 7.5\)](#), but we fit the model without including the `exp2` and `wks` variables.

We first fit the model with `xhtaylor` and then with `xtreg, fe`:

```
. use http://www.stata-press.com/data/r13/psidextract
. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed)
(output omitted)
. estimates store eq_ht
. xtreg lwage occ south smsa ind exp ms union fem blk ed, fe
(output omitted)
. estimates store eq_fe
```

We can now use `hausman` to compare the two estimators, but we need to specify the `df()` to indicate the degrees of freedom for the χ^2 statistic, which would be determined by the overidentifying restrictions in the Hausman–Taylor estimation. In this case, there are three degrees of freedom because there are four time-varying exogenous variables (`occ`, `south`, `smsa`, `ind`) that can be used as instruments for only one time-invariant endogenous variable (`ed`).


```
. hausman eq_fe eq_ht, df(3)
```

	Coefficients			
	(b) eq_fe	(B) eq_ht	(b-B) Difference	$\sqrt{\text{diag}(V_b - V_B)}$ S.E.
occ	-.0239323	-.0231694	-.0007629	.0002395
south	-.0037282	.0062699	-.0099982	.0124188
smsa	-.0436251	-.0433518	-.0002733	.0042296
ind	.021184	.0156376	.0055465	.0025159
exp	.0965738	.0964748	.0000991	.000063
ms	-.0299908	-.0300703	.0000795	.000321
union	.0349156	.0348494	.0000662	.0006336

```
b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xhtaylor
Test: Ho: difference in coefficients not systematic
      chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
              =          5.22
      Prob>chi2 =          0.1567
      (V_b-V_B is not positive definite)
```

The p -value for the test provides evidence favoring the null hypothesis; therefore, in this case, the Hausman–Taylor estimation is adequate.

Notice that the variance–covariance matrix for the difference $(b-B)$ is not positive definite. As [Greene \(2012, 237\)](#) points out, this kind of result is due to finite-sample conditions. He also states that Hausman considers it preferable to take the test statistic as zero and, therefore, not to reject the null hypothesis.

➤ **Example 2**

We now want to determine whether the Amemiya–MaCurdy estimator produces significant efficiency gains with respect to the Hausman–Taylor estimator. We refit the two models, and we use the Hausman test again:

```
. use http://www.stata-press.com/data/r13/psidextract
. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed)
(output omitted)
. estimates store eq_ht
. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed) amacurdy
(output omitted)
. estimates store eq_am
```



```
. hausman eq_ht eq_am
```

	Coefficients		(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	(b) eq_ht	(B) eq_am		
occ	-.0231694	-.023354	.0001846	.0006485
south	.0062699	.0060857	.0001842	.0010641
smsa	-.0433518	-.0434638	.0001121	.0006297
ind	.0156376	.0156602	-.0000226	.000492
exp	.0964748	.0962147	.00026	.0000694
ms	-.0300703	-.0303139	.0002436	.0006735
union	.0348494	.0345742	.0002752	.0006471
fem	-.1277756	-.1287857	.0010101	.0036717
blk	-.2911574	-.291645	.0004876	.0082831
ed	.1390257	.1380699	.0009558	.005436

b = consistent under Ho and Ha; obtained from xhtaylor

B = inconsistent under Ha, efficient under Ho; obtained from xhtaylor

Test: Ho: difference in coefficients not systematic

$\chi^2(10) = (b-B)'[(V_b-V_B)^{-1}](b-B)$

= 14.42

Prob>chi2 = 0.1548

The result indicates that we should use the more efficient estimation produced by the Amemiya–MaCurdy estimator.



References

Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.

Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.

Also see

[XT] [xhtaylor](#) — Hausman–Taylor estimator for error-components models

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtintreg depvarlower depvarupper [indepvars] [if] [in] [weight] [, options]
```

<i>options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be oim, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>intreg</u>	perform likelihood-ratio test against pooled model
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is intpoints(12)
Maximization	
<u>maximize_options</u>	control the maximization process; see [R] <u>maximize</u>
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; use xtset; see [XT] xtset.
indepvars may contain factor variables; see [U] **11.4.3 Factor variables**.
*depvar*_{lower}, *depvar*_{upper}, and *indepvars* may contain time-series operators; see [U] **11.4.4 Time-series varlists**.
by and statsby are allowed; see [U] **11.1.10 Prefix commands**.
iweights are allowed; see [U] **11.1.6 weight**. Weights must be constant within panel.
coeflegend does not appear in the dialog box.
See [U] **20 Estimation and postestimation commands** for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Censored outcomes > Interval regression (RE)

Description

`xtintreg` fits a random-effects regression model whose dependent variable may be measured as point data, interval data, left-censored data, or right-censored data. `depvarlower` and `depvarupper` represent how the dependent variable was measured.

The values in `depvarlower` and `depvarupper` should have the following form:

Type of data		<code>depvar_{lower}</code>	<code>depvar_{upper}</code>
point data	$a = [a, a]$	a	a
interval data	$[a, b]$	a	b
left-censored data	$(-\infty, b]$.	b
right-censored data	$[a, +\infty)$	a	.

Options

Model

`noconstant`, `offset(varname)`, `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Reporting

`level(#)`, `noskip`; see [R] [estimation options](#).

`intreg` specifies that a likelihood-ratio test comparing the random-effects model with the pooled (`intreg`) model be included in the output.

`nocnsreport`; see [R] [estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrntolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtintreg` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Remarks and examples

Consider the linear regression model with panel-level random effects

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it}$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$. The random effects, ν_i , are i.i.d., $N(0, \sigma_\nu^2)$, and ϵ_{it} are i.i.d., $N(0, \sigma_\epsilon^2)$ independently of ν_i . The observed data consist of the couples, (y_{1it}, y_{2it}) , such that all that is known is that $y_{1it} \leq y_{it} \leq y_{2it}$, where y_{1it} is possibly $-\infty$ and y_{2it} is possibly $+\infty$.

► Example 1

We begin with the `nlswork` dataset described in [XT] `xt` and create two fictional dependent variables, where the wages are instead reported sometimes as ranges. The wages have been adjusted to 1988 dollars and have further been recoded such that some of the observations are known exactly, some are left-censored, some are right-censored, and some are known only in an interval.

We wish to fit a random-effects interval regression model of adjusted (log) wages:

```
. use http://www.stata-press.com/data/r13/nlswork5
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtintreg ln_wage1 ln_wage2 union age grade south##c.year occ_code, intreg
(output omitted)

Random-effects interval regression      Number of obs      =      19151
Group variable: idcode                 Number of groups    =      4140
Random effects u_i ~ Gaussian          Obs per group: min =           1
                                       avg   =          4.6
                                       max   =           12

Integration method: mvaghermite        Integration points =           12
                                       Wald chi2(7)       =      2523.84
Log likelihood = -23174.355             Prob > chi2        =       0.0000
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
union	.1441844	.0094245	15.30	0.000	.1257128	.162656
age	.0104083	.0018804	5.54	0.000	.0067228	.0140939
grade	.0794958	.0023469	33.87	0.000	.074896	.0840955
1.south	-.3778103	.0979415	-3.86	0.000	-.5697722	-.1858485
year	.0013528	.0020176	0.67	0.503	-.0026016	.0053071
south#c.year						
1	.0034385	.0012105	2.84	0.005	.0010659	.005811
occ_code	-.0197912	.0014094	-14.04	0.000	-.0225535	-.0170289
_cons	.3791078	.1136641	3.34	0.001	.1563303	.6018853
/sigma_u	.2987074	.0052697	56.68	0.000	.2883789	.309036
/sigma_e	.3528109	.0030935	114.05	0.000	.3467478	.358874
rho	.4175266	.0102529			.3975474	.4377211

Likelihood-ratio test of sigma_u=0: chibar2(01)= 2516.85 Prob>=chibar2 = 0.000


```

Observation summary:    4757  left-censored observations
                        4792  uncensored observations
                        4830  right-censored observations
                        4772  interval observations

```

The output includes the overall and panel-level variance components (labeled `sigma_e` and `sigma_u`, respectively) together with ρ (labeled `rho`),

$$\rho = \frac{\sigma_u^2}{\sigma_e^2 + \sigma_u^2}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When `rho` is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (`intreg`) with the panel estimator.

◀

□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] [quadchk](#) for details and [XT] [xtprobit](#) for an [example](#).

Because the `xtintreg` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

□

Stored results

`xtintreg` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_unc)</code>	number of uncensored observations
<code>e(N_lrc)</code>	number of left-censored observations
<code>e(N_rc)</code>	number of right-censored observations
<code>e(N_int)</code>	number of interval observations
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(rho)</code>	ρ
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtintreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	names of dependent variables
<code>e(ivar)</code>	variable denoting groups
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset1)</code>	offset
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

Assuming a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i , we have the joint (unconditional of ν_i) density of the observed data for the i th panel

$$f\{(y_{1i1}, y_{2i1}), \dots, (y_{1in_i}, y_{2in_i}) | \mathbf{x}_{1i}, \dots, \mathbf{x}_{in_i}\} = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y_{1it}, y_{2it}, \Delta_{it}) = \begin{cases} (\sqrt{2\pi}\sigma_\epsilon)^{-1} e^{-(y_{1it}-\Delta_{it})^2/(2\sigma_\epsilon^2)} & \text{if } (y_{1it}, y_{2it}) \in C \\ \Phi\left(\frac{y_{2it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in L \\ 1 - \Phi\left(\frac{y_{1it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in R \\ \Phi\left(\frac{y_{2it}-\Delta_{it}}{\sigma_\epsilon}\right) - \Phi\left(\frac{y_{1it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in I \end{cases}$$

where C is the set of noncensored observations ($y_{1it} = y_{2it}$ and both nonmissing), L is the set of left-censored observations (y_{1it} missing and y_{2it} nonmissing), R is the set of right-censored observations (y_{1it} nonmissing and y_{2it} missing), I is the set of interval observations ($y_{1it} < y_{2it}$ and both nonmissing), and $\Phi(\cdot)$ is the cumulative normal distribution.

The panel-level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{1it}, y_{2it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, using the definition of $g(y_{1it}, y_{2it}, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right]$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of $1e-6$; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option:

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log f \{ (y_{1i1}, y_{2i1}), \dots, (y_{1in_i}, y_{2in_i}) | \mathbf{x}_{1i}, \dots, \mathbf{x}_{in_i} \} \\ &\approx \sum_{i=1}^n w_i \log \left\{ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left(y_{1it}, y_{2it}, \mathbf{x}_{it}\beta + \sqrt{2\sigma_\nu}a_m^* \right) \right\} \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

References

- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.

Also see

- [XT] [xtintreg postestimation](#) — Postestimation tools for `xtintreg`
- [XT] [quadchk](#) — Check sensitivity of quadrature approximation
- [XT] [xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] [xtset](#) — Declare data to be panel data
- [XT] [xttobit](#) — Random-effects tobit models
- [R] [intreg](#) — Interval regression
- [R] [tobit](#) — Tobit regression
- [U] [20 Estimation and postestimation commands](#)

Description
Remarks and examples

Syntax for predict
Also see

Menu for predict

Options for predict

Description

The following postestimation commands are available after `xtintreg`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance-covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	linear prediction assuming a zero random effect, the default
<code>stdp</code>	standard error of the linear prediction
<code>stdf</code>	standard error of the linear forecast
<code>pr0(<i>a</i>,<i>b</i>)</code>	$\Pr(a < y < b)$ assuming a zero random effect
<code>e0(<i>a</i>,<i>b</i>)</code>	$E(y \mid a < y < b)$ assuming a zero random effect
<code>ystar0(<i>a</i>,<i>b</i>)</code>	$E(y^*), y^* = \max\{a, \min(y_j, b)\}$ assuming a zero random effect

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

where a and b may be numbers or variables; a missing ($a \geq .$) means $-\infty$, and b missing ($b \geq .$) means $+\infty$; see [U] [12.2.1 Missing values](#).

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

stdp calculates the standard error of the linear prediction. It can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value.

stdf calculates the standard error of the linear forecast. This is the standard error of the point prediction for 1 observation. It is commonly referred to as the standard error of the future or forecast value. By construction, the standard errors produced by **stdf** are always larger than those produced by **stdp**; see [Methods and formulas](#) in [R] **regress**.

pr0(a,b) calculates estimates of $\Pr(a < y < b | \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, which is the probability that y would be observed in the interval (a, b) , given the current values of the predictors, \mathbf{x}_{it} , and given a zero random effect. In the discussion that follows, these two conditions are implied.

a and b may be specified as numbers or variable names; lb and ub are variable names;

pr0(20,30) calculates $\Pr(20 < y < 30)$;

pr0(lb,ub) calculates $\Pr(lb < y < ub)$; and

pr0(20,ub) calculates $\Pr(20 < y < ub)$.

a missing ($a \geq .$) means $-\infty$; **pr0(.,30)** calculates $\Pr(-\infty < y < 30)$;

pr0(lb,30) calculates $\Pr(-\infty < y < 30)$ in observations for which $lb \geq .$
(and calculates $\Pr(lb < y < 30)$ elsewhere).

b missing ($b \geq .$) means $+\infty$; **pr0(20,.)** calculates $\Pr(+\infty > y > 20)$;

pr0(20,ub) calculates $\Pr(+\infty > y > 20)$ in observations for which $ub \geq .$
(and calculates $\Pr(20 < y < ub)$ elsewhere).

e0(a,b) calculates estimates of $E(y | a < y < b, \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, which is the expected value of y conditional on y being in the interval (a, b) , meaning that y is truncated. a and b are specified as they are for **pr0()**.

ystar(a,b) calculates estimates of $E(y^* | \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, where $y^* = a$ if $y \leq a$, $y^* = b$ if $y \geq b$, and $y^* = y$ otherwise, meaning that y^* is the censored version of y . a and b are specified as they are for **pr0()**.

nooffset is relevant only if you specified **offset(varname)** for **xtintreg**. It modifies the calculations made by **predict** so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [XT] **xtintreg**, we fit a random-effects model of wages. Say that we want to know how union membership status affects the probability that a worker's wage will be “low”, where low means a log wage that is less than the 20th percentile of all observations in our dataset. First, we use **centile** to find the 20th percentile of `ln_wage`:

```
. use http://www.stata-press.com/data/r13/nlswork5
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtintreg ln_wage1 ln_wage2 i.union age grade south##c.year, intreg
(output omitted)
. centile ln_wage, centile(20)
```

Variable	Obs	Percentile	Centile	— Binom. Interp. — [95% Conf. Interval]	
ln_wage	28534	20	1.301507	1.297063	1.308635

Now we use **margins** to obtain the effect of union status on the probability that the log of wages is in the bottom 20% of women. Given the results from **centile** that corresponds to the log of wages being below 1.30. We evaluate the effect for two groups: 1) women age 30 living in the south in 1988 who graduated high school, but had no more schooling, and 2) the same group of women, with the exception that they are college graduates (`grade=16`).

```
. margins, dydx(union) predict(pr0(.,1.30))
> at(age=30 south=1 year=88 grade=12 union=0)
> at(age=30 south=1 year=88 grade=16 union=0)

Conditional marginal effects      Number of obs   =      19224
Model VCE      : OIM

Expression      : Pr(ln_wage1<1.30), predict(pr0(.,1.30))
dy/dx w.r.t.    : 1.union

1._at           : union           =           0
                  age             =          30
                  grade            =          12
                  south            =           1
                  year             =          88

2._at           : union           =           0
                  age             =          30
                  grade            =          16
                  south            =           1
                  year             =          88
```

	Delta-method					
	dy/dx	Std. Err.	z	P> z	[95% Conf. Interval]	
1.union						
_at						
1	-.0787117	.0060655	-12.98	0.000	-.0905999	-.0668235
2	-.0378758	.0035595	-10.64	0.000	-.0448523	-.0308993

Note: dy/dx for factor levels is the discrete change from the base level.

For the first group of women, according to our fitted model, being in a union lowers the probability of being classified as a low-wage worker by almost 7.9 percentage points. Being a college graduate attenuates this effect to just under 3.8 percentage points.

Also see

[XT] [xtintreg](#) — Random-effects interval-data regression models

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description
Options for RE model	Options for BE model	Options for FE model
Options for FD model	Remarks and examples	Stored results
Methods and formulas	Acknowledgment	References
Also see		

Syntax

GLS random-effects (RE) model

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in] [, re RE_options]
```

Between-effects (BE) model

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in] , be [BE_options]
```

Fixed-effects (FE) model

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in] , fe [FE_options]
```

First-differenced (FD) estimator

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in] , fd [FD_options]
```

RE_options	Description
Model	
re	use random-effects estimator; the default
ec2sls	use Baltagi’s EC2SLS random-effects estimator
nosa	use the Baltagi–Chang estimators of the variance components
regress	treat covariates as exogenous and ignore instrumental variables
SE	
vce(vcetype)	vcetype may be conventional, bootstrap, or jackknife
Reporting	
level(#)	set confidence level; default is level(95)
first	report first-stage estimates
small	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and χ^2 statistics
theta	report θ
display_options	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
coeflegend	display legend instead of statistics

<i>BE_options</i>	Description
<hr/>	
Model	
<code>be</code>	use between-effects estimator
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables
SE	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>first</code>	report first-stage estimates
<code>small</code>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and χ^2 statistics
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics
<hr/>	
<i>FE_options</i>	Description
<hr/>	
Model	
<code>fe</code>	use fixed-effects estimator
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables
SE	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>first</code>	report first-stage estimates
<code>small</code>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and χ^2 statistics
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics
<hr/>	

<i>FD_options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>fd</code>	use first-differenced estimator
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables
SE	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>first</code>	report first-stage estimates
<code>small</code>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and χ^2 statistics
<code>display_options</code>	control column formats, row spacing, line width, and display of omitted variables
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified. For `xtivreg`, `fd` a time variable must also be specified. Use `xtset`; see [XT] `xtset`.

`varlist1` and `varlisttv` may contain factor variables, except for the `fd` estimator; see [U] 11.4.3 Factor variables.

`devar`, `varlist1`, `varlist2`, and `varlisttv` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by` and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Instrumental-variables regression (FE, RE, BE, FD)

Description

`xtivreg` offers five different estimators for fitting panel-data models in which some of the right-hand-side covariates are endogenous. These estimators are two-stage least-squares generalizations of simple panel-data estimators for exogenous variables. `xtivreg` with the `be` option uses the two-stage least-squares between estimator. `xtivreg` with the `fe` option uses the two-stage least-squares within estimator. `xtivreg` with the `re` option uses a two-stage least-squares random-effects estimator. There are two implementations: G2SLS from Balestra and Varadharajan-Krishnakumar (1987) and EC2SLS from Baltagi. The Balestra and Varadharajan-Krishnakumar G2SLS is the default because it is computationally less expensive. Baltagi's EC2SLS can be obtained by specifying the `ec2sls` option. `xtivreg` with the `fd` option requests the two-stage least-squares first-differenced estimator.

See Baltagi (2013) for an introduction to panel-data models with endogenous covariates. For the derivation and application of the first-differenced estimator, see Anderson and Hsiao (1981).

Options for RE model

Model

re requests the G2SLS random-effects estimator. **re** is the default.

ec2sls requests Baltagi's EC2SLS random-effects estimator instead of the default Balestra and Varadharajan-Krishnakumar estimator.

nosa specifies that the Baltagi–Chang estimators of the variance components be used instead of the default adapted Swamy–Arora estimators.

regress specifies that all the covariates be treated as exogenous and that the instrument list be ignored. Specifying **regress** causes **xtivreg** to fit the requested panel-data regression model of *depvar* on *varlist*₁ and *varlist*₂, ignoring *varlist*_{iv}.

SE

vce(*vcetype*) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (**conventional**) and that use bootstrap or jackknife methods (**bootstrap**, **jackknife**); see [XT] [vce_options](#).

vce(**conventional**), the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

level(#); see [R] [estimation options](#).

first specifies that the first-stage regressions be displayed.

small specifies that *t* statistics be reported instead of *Z* statistics and that *F* statistics be reported instead of χ^2 statistics.

theta specifies that the output include the estimated value of θ used in combining the between and fixed estimators. For balanced data, this is a constant, and for unbalanced data, a summary of the values is presented in the header of the output.

display_options: **noomitted**, **vsquish**, **noemptycells**, **baselevels**, **allbaselevels**, **nofvlabel**, **fvwrap**(#), **fvwrapon**(*style*), **cformat**(%*fnt*), **pformat**(%*fnt*), **sformat**(%*fnt*), and **nolstretch**; see [R] [estimation options](#).

The following option is available with **xtivreg** but is not shown in the dialog box:

coeflegend; see [R] [estimation options](#).

Options for BE model

Model

be requests the between regression estimator.

regress specifies that all the covariates are to be treated as exogenous and that the instrument list is to be ignored. Specifying **regress** causes **xtivreg** to fit the requested panel-data regression model of *depvar* on *varlist*₁ and *varlist*₂, ignoring *varlist*_{iv}.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level(#)`; see [R] [estimation options](#).

`first` specifies that the first-stage regressions be displayed.

`small` specifies that t statistics be reported instead of Z statistics and that F statistics be reported instead of χ^2 statistics.

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

The following option is available with `xtivreg` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for FE model

Model

`fe` requests the fixed-effects (within) regression estimator.

`regress` specifies that all the covariates are to be treated as exogenous and that the instrument list is to be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of *depvar* on *varlist*₁ and *varlist*₂, ignoring *varlist*_{iv}.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level(#)`; see [R] [estimation options](#).

`first` specifies that the first-stage regressions be displayed.

`small` specifies that t statistics be reported instead of Z statistics and that F statistics be reported instead of χ^2 statistics.

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

The following option is available with `xtivreg` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Options for FD model

Model

`noconstant`; see [R] [estimation options](#).

`fd` requests the first-differenced regression estimator.

`regress` specifies that all the covariates are to be treated as exogenous and that the instrument list is to be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of *depvar* on *varlist*₁ and *varlist*₂, ignoring *varlist*_{iv}.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level(#)`; see [R] [estimation options](#).

`first` specifies that the first-stage regressions be displayed.

`small` specifies that *t* statistics be reported instead of *Z* statistics and that *F* statistics be reported instead of χ^2 statistics.

display_options: `noomitted`, `vsquish`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no1stretch`; see [R] [estimation options](#).

The following option is available with `xtivreg` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Remarks and examples

If you have not read [XT] [xt](#), please do so.

Consider an equation of the form

$$y_{it} = \mathbf{Y}_{it}\boldsymbol{\gamma} + \mathbf{X}_{1it}\boldsymbol{\beta} + \mu_i + \nu_{it} = \mathbf{Z}_{it}\boldsymbol{\delta} + \mu_i + \nu_{it} \quad (1)$$

where

y_{it} is the dependent variable;

\mathbf{Y}_{it} is an $1 \times g_2$ vector of observations on g_2 endogenous variables included as covariates, and these variables are allowed to be correlated with the ν_{it} ;

\mathbf{X}_{1it} is an $1 \times k_1$ vector of observations on the exogenous variables included as covariates;

$$\mathbf{Z}_{it} = [\mathbf{Y}_{it} \ \mathbf{X}_{it}];$$

γ is a $g_2 \times 1$ vector of coefficients;

β is a $k_1 \times 1$ vector of coefficients; and

δ is a $K \times 1$ vector of coefficients, where $K = g_2 + k_1$.

Assume that there is a $1 \times k_2$ vector of observations on the k_2 instruments in \mathbf{X}_{2it} . The order condition is satisfied if $k_2 \geq g_2$. Let $\mathbf{X}_{it} = [\mathbf{X}_{1it} \ \mathbf{X}_{2it}]$. `xtivreg` handles exogenously unbalanced panel data. Thus define T_i to be the number of observations on panel i , n to be the number of panels and N to be the total number of observations; that is, $N = \sum_{i=1}^n T_i$.

`xtivreg` offers five different estimators, which may be applied to models having the form of (1). The first-differenced estimator (FD2SLS) removes the μ_i by fitting the model in first differences. The within estimator (FE2SLS) fits the model after sweeping out the μ_i by removing the panel-level means from each variable. The between estimator (BE2SLS) models the panel averages. The two random-effects estimators, G2SLS and EC2SLS, treat the μ_i as random variables that are independent and identically distributed (i.i.d.) over the panels. Except for (FD2SLS), all of these estimators are generalizations of estimators in `xtreg`. See [XT] `xtreg` for a discussion of these estimators for exogenous covariates.

Although the estimators allow for different assumptions about the μ_i , all the estimators assume that the idiosyncratic error term ν_{it} has zero mean and is uncorrelated with the variables in \mathbf{X}_{it} . Just as when there are no endogenous covariates, as discussed in [XT] `xtreg`, there are various perspectives on what assumptions should be placed on the μ_i . If they are assumed to be fixed, the μ_i may be correlated with the variables in \mathbf{X}_{it} , and the within estimator is efficient within a class of limited information estimators. Alternatively, if the μ_i are assumed to be random, they are also assumed to be i.i.d. over the panels. If the μ_i are assumed to be uncorrelated with the variables in \mathbf{X}_{it} , the GLS random-effects estimators are more efficient than the within estimator. However, if the μ_i are correlated with the variables in \mathbf{X}_{it} , the random-effects estimators are inconsistent but the within estimator is consistent. The price of using the within estimator is that it is not possible to estimate coefficients on time-invariant variables, and all inference is conditional on the μ_i in the sample. See Mundlak (1978) and Hsiao (2003) for discussions of this interpretation of the within estimator.

► Example 1: Fixed-effects model

For the within estimator, consider another version of the wage equation discussed in [XT] `xtreg`. The data for this example come from an extract of women from the National Longitudinal Survey of Youth that was described in detail in [XT] `xt`. Restricting ourselves to only time-varying covariates, we might suppose that the log of the real wage was a function of the individual's age, age², her tenure in the observed place of employment, whether she belonged to union, whether she lives in metropolitan area, and whether she lives in the south. The variables for these are, respectively, `age`, `c.age#c.age`, `tenure`, `union`, `not_smsa`, and `south`. If we treat all the variables as exogenous, we can use the one-stage within estimator from `xtreg`, yielding


```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtreg ln_w age c.age#c.age tenure not_smsa union south, fe

Fixed-effects (within) regression              Number of obs   =   19007
Group variable: idcode                       Number of groups =    4134

R-sq:  within = 0.1333                      Obs per group: min =     1
        between = 0.2375                      avg           =    4.6
        overall = 0.2031                      max           =    12

                                           F(6,14867)      =   381.19
                                           Prob > F         =    0.0000

corr(u_i, Xb) = 0.2074
```

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
age	.0311984	.0033902	9.20	0.000	.0245533	.0378436
c.age#c.age	-.0003457	.0000543	-6.37	0.000	-.0004522	-.0002393
tenure	.0176205	.0008099	21.76	0.000	.0160331	.0192079
not_smsa	-.0972535	.0125377	-7.76	0.000	-.1218289	-.072678
union	.0975672	.0069844	13.97	0.000	.0838769	.1112576
south	-.0620932	.013327	-4.66	0.000	-.0882158	-.0359706
_cons	1.091612	.0523126	20.87	0.000	.9890729	1.194151
sigma_u	.3910683	(fraction of variance due to u_i)				
sigma_e	.25545969					
rho	.70091004					

F test that all u_i=0: F(4133, 14867) = 8.31 Prob > F = 0.0000

All the coefficients are statistically significant and have the expected signs.

Now suppose that we wish to model tenure as a function of union and south and that we believe that the errors in the two equations are correlated. Because we are still interested in the within estimates, we now need a two-stage least-squares estimator. The following output shows the command and the results from fitting this model:


```
. xtivreg ln_w age c.age#c.age not_smsa (tenure = union south), fe
Fixed-effects (within) IV regression      Number of obs      =      19007
Group variable: idcode                   Number of groups    =      4134
R-sq:  within = .                               Obs per group: min =      1
      between = 0.1304                           avg =              4.6
      overall  = 0.0897                           max =              12
                                           Wald chi2(4)        =    147926.58
corr(u_i, Xb) = -0.6843                       Prob > chi2         =      0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
tenure	.2403531	.0373419	6.44	0.000	.1671643	.3135419
age	.0118437	.0090032	1.32	0.188	-.0058023	.0294897
c.age#c.age	-.0012145	.0001968	-6.17	0.000	-.0016003	-.0008286
not_smsa	-.0167178	.0339236	-0.49	0.622	-.0832069	.0497713
_cons	1.678287	.1626657	10.32	0.000	1.359468	1.997106
sigma_u	.70661941					
sigma_e	.63029359					
rho	.55690561	(fraction of variance due to u_i)				
F test that all u_i=0:		F(4133,14869) =		1.44	Prob > F	= 0.0000
Instrumented:	tenure					
Instruments:	age c.age#c.age not_smsa union south					

Although all the coefficients still have the expected signs, the coefficients on `age` and `not_smsa` are no longer statistically significant. Given that these variables have been found to be important in many other studies, we might want to rethink our specification. ◀

If we are willing to assume that the μ_i are uncorrelated with the other covariates, we can fit a random-effects model. The model is frequently known as the variance-components or error-components model. `xtivreg` has estimators for two-stage least-squares one-way error-components models. In the one-way framework, there are two variance components to estimate, the variance of the μ_i and the variance of the ν_{it} . Because the variance components are unknown, consistent estimates are required to implement feasible GLS. `xtivreg` offers two choices: a Swamy–Arora method and simple consistent estimators from Baltagi and Chang (2000).

Baltagi and Chang (1994) derived the Swamy–Arora estimators of the variance components for unbalanced panels. By default, `xtivreg` uses estimators that extend these unbalanced Swamy–Arora estimators to the case with instrumental variables. The default Swamy–Arora method contains a degree-of-freedom correction to improve its performance in small samples. Baltagi and Chang (2000) use variance-components estimators, which are based on the ideas of Amemiya (1971) and Swamy and Arora (1972), but they do not attempt to make small-sample adjustments. These consistent estimators of the variance components will be used if the `nosa` option is specified.

Using either estimator of the variance components, `xtivreg` offers two GLS estimators of the random-effects model. These two estimators differ only in how they construct the GLS instruments from the exogenous and instrumental variables contained in $\mathbf{X}_{it} = [\mathbf{X}_{1it} \ \mathbf{X}_{2it}]$. The default method, G2SLS, which is from Balestra and Varadharajan-Krishnakumar, uses the exogenous variables after they have been passed through the feasible GLS transform. In math, G2SLS uses \mathbf{X}_{it}^* for the GLS instruments, where \mathbf{X}_{it}^* is constructed by passing each variable in \mathbf{X}_{it} through the GLS transform in (3) given in *Methods and formulas*. If the `ec2sls` option is specified, `xtivreg` performs Baltagi's

EC2SLS. In EC2SLS, the instruments are $\tilde{\mathbf{X}}_{it}$ and $\overline{\mathbf{X}}_{it}$, where $\tilde{\mathbf{X}}_{it}$ is constructed by passing each of the variables in \mathbf{X}_{it} through the within transform, and $\overline{\mathbf{X}}_{it}$ is constructed by passing each variable through the between transform. The within and between transforms are given in the [Methods and formulas](#) section. Baltagi and Li (1992) show that, although the G2SLS instruments are a subset of those contained in EC2SLS, the extra instruments in EC2SLS are redundant in the sense of White (2001). Given the extra computational cost, G2SLS is the default.

► Example 2: GLS random-effects model

Here is the output from applying the G2SLS estimator to this model:

```
. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), re
G2SLS random-effects IV regression           Number of obs   =   19007
Group variable: idcode                       Number of groups  =    4134
R-sq:   within  = 0.0664                     Obs per group: min =     1
        between = 0.2098                      avg           =    4.6
        overall  = 0.1463                      max           =    12

corr(u_i, X)      = 0 (assumed)               Wald chi2(5)      =   1446.37
                                                Prob > chi2       =    0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
tenure	.1391798	.0078756	17.67	0.000	.123744	.1546157
age	.0279649	.0054182	5.16	0.000	.0173454	.0385843
c.age#c.age	-.0008357	.0000871	-9.60	0.000	-.0010063	-.000665
not_smsa	-.2235103	.0111371	-20.07	0.000	-.2453386	-.2016821
race						
black	-.2078613	.0125803	-16.52	0.000	-.2325183	-.1832044
_cons	1.337684	.0844988	15.83	0.000	1.172069	1.503299
sigma_u	.36582493					
sigma_e	.63031479					
rho	.25197078	(fraction of variance due to u_i)				

```
Instrumented:  tenure
Instruments:   age c.age#c.age not_smsa 2.race union birth_yr south
```

We have included two time-invariant covariates, `birth_yr` and `2.race`. All the coefficients are statistically significant and are of the expected sign.

Applying the EC2SLS estimator yields similar results:

```
. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), re
> ec2sls
```

EC2SLS random-effects IV regression	Number of obs	=	19007		
Group variable: idcode	Number of groups	=	4134		
R-sq: within	=	0.0898	Obs per group: min	=	1
between	=	0.2608	avg	=	4.6
overall	=	0.1926	max	=	12
corr(u_i, X)	=	0 (assumed)	Wald chi2(5)	=	2721.92
			Prob > chi2	=	0.0000

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
tenure	.064822	.0025647	25.27	0.000	.0597953	.0698486
age	.0380048	.0039549	9.61	0.000	.0302534	.0457562
c.age#c.age	-.0006676	.0000632	-10.56	0.000	-.0007915	-.0005438
not_smsa	-.2298961	.0082993	-27.70	0.000	-.2461625	-.2136297
race						
black	-.1823627	.0092005	-19.82	0.000	-.2003954	-.16433
_cons	1.110564	.0606538	18.31	0.000	.9916849	1.229443
sigma_u	.36582493					
sigma_e	.63031479					
rho	.25197078	(fraction of variance due to u_i)				
Instrumented:	tenure					
Instruments:	age c.age#c.age not_smsa 2.race union birth_yr south					

Fitting the same model as above with the G2SLS estimator and the consistent variance components estimators yields


```
. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), re
> nosa

G2SLS random-effects IV regression
Group variable: idcode
Number of obs      =      19007
Number of groups   =      4134
R-sq:  within      =  0.0664
       between     =  0.2098
       overall      =  0.1463
Obs per group: min =         1
               avg  =        4.6
               max  =        12
Wald chi2(5)       =     1446.93
Prob > chi2        =      0.0000

corr(u_i, X)      =  0 (assumed)
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
tenure	.1391859	.007873	17.68	0.000	.1237552	.1546166
age	.0279697	.005419	5.16	0.000	.0173486	.0385909
c.age#c.age	-.0008357	.0000871	-9.60	0.000	-.0010064	-.000665
not_smsa	-.2235738	.0111344	-20.08	0.000	-.2453967	-.2017508
race						
black	-.2078733	.0125751	-16.53	0.000	-.2325201	-.1832265
_cons	1.337522	.0845083	15.83	0.000	1.171889	1.503155
sigma_u	.36535633					
sigma_e	.63020883					
rho	.2515512	(fraction of variance due to u_i)				

Instrumented: tenure
Instruments: age c.age#c.age not_smsa 2.race union birth_yr south

➤ **Example 3: First-differenced estimator**

The two-stage least-squares first-differenced estimator (FD2SLS) has been used to fit both fixed-effect and random-effect models. If the μ_i are truly fixed-effects, the FD2SLS estimator is not as efficient as the two-stage least-squares within estimator for finite T_i . Similarly, if none of the endogenous variables are lagged dependent variables, the exogenous variables are all strictly exogenous, and the random effects are i.i.d. and independent of the \mathbf{X}_{it} , the two-stage GLS estimators are more efficient than the FD2SLS estimator. However, the FD2SLS estimator has been used to obtain consistent estimates when one of these conditions fails. [Anderson and Hsiao \(1981\)](#) used a version of the FD2SLS estimator to fit a panel-data model with a lagged dependent variable.

[Arellano and Bond \(1991\)](#) develop new one-step and two-step GMM estimators for dynamic panel data. See [\[XT\] xtabond](#) for a discussion of these estimators and Stata’s implementation of them. In their article, [Arellano and Bond \(1991\)](#) apply their new estimators to a model of dynamic labor demand that had previously been considered by [Layard and Nickell \(1986\)](#). They also compare the results of their estimators with those from the Anderson–Hsiao estimator using data from an unbalanced panel of firms from the United Kingdom. As is conventional, all variables are indexed over the firm i and time t . In this dataset, n_{it} is the log of employment in firm i inside the United Kingdom at time t , w_{it} is the natural log of the real product wage, k_{it} is the natural log of the gross capital stock, and ys_{it} is the natural log of industry output. The model also includes time dummies `yr1980`, `yr1981`, `yr1982`, `yr1983`, and `yr1984`. In [Arellano and Bond \(1991, table 5, column e\)](#), the authors present the results from applying one version of the Anderson–Hsiao estimator to these data. This example reproduces their results for the coefficients, though standard errors are different because Arellano and Bond are using robust standard errors.


```
. use http://www.stata-press.com/data/r13/abdata
. xtivreg n l2.n l(0/1).w l(0/2).(k ys) yr1981-yr1984 (l.n = l3.n), fd
```

First-differenced IV regression

Group variable:	id	Number of obs	=	471
Time variable:	year	Number of groups	=	140
R-sq: within	= 0.0141	Obs per group: min	=	3
between	= 0.9165	avg	=	3.4
overall	= 0.9892	max	=	5
		Wald chi2(14)	=	122.53
corr(u_i, Xb)	= 0.9239	Prob > chi2	=	0.0000

D.n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
LD.	1.422765	1.583053	0.90	0.369	-1.679962	4.525493
L2D.	-.1645517	.1647179	-1.00	0.318	-.4873928	.1582894
w						
D1.	-.7524675	.1765733	-4.26	0.000	-1.098545	-.4063902
LD.	.9627611	1.086506	0.89	0.376	-1.166752	3.092275
k						
D1.	.3221686	.1466086	2.20	0.028	.0348211	.6095161
LD.	-.3248778	.5800599	-0.56	0.575	-1.461774	.8120187
L2D.	-.0953947	.1960883	-0.49	0.627	-.4797207	.2889314
ys						
D1.	.7660906	.369694	2.07	0.038	.0415037	1.490678
LD.	-1.361881	1.156835	-1.18	0.239	-3.629237	.9054744
L2D.	.3212993	.5440403	0.59	0.555	-.745	1.387599
yr1981						
D1.	-.0574197	.0430158	-1.33	0.182	-.1417291	.0268896
yr1982						
D1.	-.0882952	.0706214	-1.25	0.211	-.2267106	.0501203
yr1983						
D1.	-.1063153	.10861	-0.98	0.328	-.319187	.1065563
yr1984						
D1.	-.1172108	.15196	-0.77	0.441	-.4150468	.1806253
_cons	.0161204	.0336264	0.48	0.632	-.0497861	.082027
sigma_u	.29069213					
sigma_e	.18855982					
rho	.70384993	(fraction of variance due to u_i)				

```
Instrumented: L.n
Instruments: L2.n w L.w k L.k L2.k ys L.ys L2.ys yr1981 yr1982 yr1983
yr1984 L3.n
```


Stored results

`xtivreg`, `re` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(df_rz)</code>	residual degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if panels balanced; 0 otherwise
<code>e(sigma)</code>	ancillary parameter (γ , <code>lnormal</code>)
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(r2_w)</code>	R -squared for within model
<code>e(r2_o)</code>	R -squared for overall model
<code>e(r2_b)</code>	R -squared for between model
<code>e(chi2)</code>	χ^2
<code>e(rho)</code>	ρ
<code>e(F)</code>	model F (small only)
<code>e(m_p)</code>	p -value from model test
<code>e(thta_min)</code>	minimum θ
<code>e(thta_5)</code>	θ , 5th percentile
<code>e(thta_50)</code>	θ , 50th percentile
<code>e(thta_95)</code>	θ , 95th percentile
<code>e(thta_max)</code>	maximum θ
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xtivreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	<code>g2s1s</code> or <code>ec2s1s</code>
<code>e(small)</code>	small, if specified
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtivreg`, `be` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(mss)</code>	model sum of squares
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom
<code>e(df_rz)</code>	residual degrees of freedom for the between-transformed regression
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rs_a)</code>	adjusted R^2
<code>e(r2_w)</code>	R -squared for within model
<code>e(r2_o)</code>	R -squared for overall model
<code>e(r2_b)</code>	R -squared for between model
<code>e(chi2)</code>	model Wald
<code>e(chi2_p)</code>	p -value for model χ^2 test
<code>e(F)</code>	F statistic (small only)
<code>e(rmse)</code>	root mean squared error
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xtivreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	<code>be</code>
<code>e(small)</code>	small, if specified
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

xtivreg, **fe** stores the following in **e()**:

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(rss)	residual sum of squares
e(df_r)	residual degrees of freedom (small only)
e(df_rz)	residual degrees of freedom for the within-transformed regression
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(sigma)	ancillary parameter (γ , \lnormal)
e(corr)	$\text{corr}(u_i, Xb)$
e(sigma_u)	panel-level standard deviation
e(sigma_e)	standard deviation of ϵ_{it}
e(r2_w)	R -squared for within model
e(r2_o)	R -squared for overall model
e(r2_b)	R -squared for between model
e(chi2)	model Wald (not small)
e(df_b)	degrees of freedom for χ^2 statistic
e(chi2_p)	p -value for model χ^2 statistic
e(rho)	ρ
e(F)	F statistic (small only)
e(F_f)	F for $H_0: u_i=0$
e(F_fp)	p -value for F for $H_0: u_i=0$
e(df_a)	degrees of freedom for absorbed effect
e(rank)	rank of e(V)

Macros

e(cmd)	xtivreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(insts)	instruments
e(instd)	instrumented variables
e(model)	fe
e(small)	small, if specified
e(vce)	<i>vcetype</i> specified in vce()
e(vcetype)	title used to label Std. Err.
e(properties)	b V
e(predict)	program used to implement predict
e(marginsok)	predictions allowed by margins
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
------------------	-------------------------

`xtivreg, fd` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom (small only)
<code>e(df_rz)</code>	residual degrees of freedom for first-differenced regression
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(sigma)</code>	ancillary parameter (γ , \lnormal)
<code>e(corr)</code>	$\text{corr}(u_i, Xb)$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(r2_w)</code>	R -squared for within model
<code>e(r2_o)</code>	R -squared for overall model
<code>e(r2_b)</code>	R -squared for between model
<code>e(chi2)</code>	model Wald (not small)
<code>e(df_b)</code>	degrees of freedom for the χ^2 statistic
<code>e(chi2_p)</code>	p -value for model χ^2 statistic
<code>e(rho)</code>	ρ
<code>e(F)</code>	F statistic (small only)
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xtivreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	<code>fd</code>
<code>e(small)</code>	small, if specified
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

Consider an equation of the form

$$y_{it} = \mathbf{Y}_{it}\boldsymbol{\gamma} + \mathbf{X}_{1it}\boldsymbol{\beta} + \mu_i + \nu_{it} = \mathbf{Z}_{it}\boldsymbol{\delta} + \mu_i + \nu_{it} \quad (2)$$

where

y_{it} is the dependent variable;

\mathbf{Y}_{it} is an $1 \times g_2$ vector of observations on g_2 endogenous variables included as covariates, and these variables are allowed to be correlated with the ν_{it} ;

\mathbf{X}_{1it} is an $1 \times k_1$ vector of observations on the exogenous variables included as covariates;

$\mathbf{Z}_{it} = [\mathbf{Y}_{it} \ \mathbf{X}_{1it}]$;

$\boldsymbol{\gamma}$ is a $g_2 \times 1$ vector of coefficients;

$\boldsymbol{\beta}$ is a $k_1 \times 1$ vector of coefficients; and

$\boldsymbol{\delta}$ is a $K \times 1$ vector of coefficients, where $K = g_2 + k_1$.

Assume that there is a $1 \times k_2$ vector of observations on the k_2 instruments in \mathbf{X}_{2it} . The order condition is satisfied if $k_2 \geq g_2$. Let $\mathbf{X}_{it} = [\mathbf{X}_{1it} \ \mathbf{X}_{2it}]$. **xtivreg** handles exogenously unbalanced panel data. Thus define T_i to be the number of observations on panel i , n to be the number of panels, and N to be the total number of observations; that is, $N = \sum_{i=1}^n T_i$.

Methods and formulas are presented under the following headings:

xtivreg, fd
xtivreg, fe
xtivreg, be
xtivreg, re

xtivreg, fd

As the name implies, this estimator obtains its estimates and conventional VCE from an instrumental-variables regression on the first-differenced data. Specifically, first differencing the data yields

$$y_{it} - y_{it-1} = (\mathbf{Z}_{it} - \mathbf{Z}_{i,t-1})\boldsymbol{\delta} + \nu_{it} - \nu_{i,t-1}$$

With the μ_i removed by differencing, we can obtain the estimated coefficients and their estimated variance–covariance matrix from a standard two-stage least-squares regression of Δy_{it} on $\Delta \mathbf{Z}_{it}$ with instruments $\Delta \mathbf{X}_{it}$.

R^2 within is reported as $\left[\text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\hat{\boldsymbol{\delta}}, y_{it} - \bar{y}_i\} \right]^2$.

R^2 between is reported as $\left\{ \text{corr}(\bar{\mathbf{Z}}_i\hat{\boldsymbol{\delta}}, \bar{y}_i) \right\}^2$.

R^2 overall is reported as $\left\{ \text{corr}(\mathbf{Z}_{it}\hat{\boldsymbol{\delta}}, y_{it}) \right\}^2$.

xtivreg, fe

At the heart of this model is the within transformation. The within transform of a variable w is

$$\tilde{w}_{it} = w_{it} - \bar{w}_i + \bar{w}$$

where

$$\bar{w}_i = \frac{1}{n} \sum_{t=1}^{T_i} w_{it}$$

$$\bar{w} = \frac{1}{N} \sum_{i=1}^n \sum_{t=1}^{T_i} w_{it}$$

and n is the number of groups and N is the total number of observations on the variable.

The within transform of (2) is

$$\tilde{y}_{it} = \tilde{\mathbf{Z}}_{it} + \tilde{\nu}_{it}$$

The within transform has removed the μ_i . With the μ_i gone, the within 2SLS estimator can be obtained from a two-stage least-squares regression of \tilde{y}_{it} on $\tilde{\mathbf{Z}}_{it}$ with instruments $\tilde{\mathbf{X}}_{it}$.

Suppose that there are K variables in \mathbf{Z}_{it} , including the mandatory constant. There are $K + n - 1$ parameters estimated in the model, and the conventional VCE for the within estimator is

$$\frac{N - K}{N - n - K + 1} V_{IV}$$

where V_{IV} is the VCE from the above two-stage least-squares regression.

From the estimate of $\hat{\boldsymbol{\delta}}$, estimates $\hat{\mu}_i$ of μ_i are obtained as $\hat{\mu}_i = \bar{y}_i - \bar{\mathbf{Z}}_i \hat{\boldsymbol{\delta}}$. Reported from the calculated $\hat{\mu}_i$ is its standard deviation and its correlation with $\bar{\mathbf{Z}}_i \hat{\boldsymbol{\delta}}$. Reported as the standard deviation of ν_{it} is the regression's estimated root mean squared error, s^2 , which is adjusted (as previously stated) for the $n - 1$ estimated means.

R^2 within is reported as the R^2 from the mean-deviated regression.

R^2 between is reported as $\left\{ \text{corr}(\bar{\mathbf{Z}}_i \hat{\boldsymbol{\delta}}, \bar{y}_i) \right\}^2$.

R^2 overall is reported as $\left\{ \text{corr}(\mathbf{Z}_{it} \hat{\boldsymbol{\delta}}, y_{it}) \right\}^2$.

At the bottom of the output, an F statistics against the null hypothesis that all the μ_i are zero is reported. This F statistic is an application of the results in [Wooldridge \(1990\)](#).

xtivreg, be

After passing (2) through the between transform, we are left with

$$\bar{y}_i = \alpha + \bar{\mathbf{Z}}_i \boldsymbol{\delta} + \mu_i + \bar{\nu}_i \quad (3)$$

where

$$\bar{w}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it} \quad \text{for } w \in \{y, \mathbf{Z}, \nu\}$$

Similarly, define $\bar{\mathbf{X}}_i$ as the matrix of instruments \mathbf{X}_{it} after they have been passed through the between transform.

The BE2SLS estimator of (3) obtains its coefficient estimates and its conventional VCE, a two-stage least-squares regression of \bar{y}_i on \bar{Z}_i with instruments \bar{X}_i in which each average appears T_i times.

R^2 between is reported as the R^2 from the fitted regression.

R^2 within is reported as $\left[\text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\hat{\delta}, y_{it} - \bar{y}_i\} \right]^2$.

R^2 overall is reported as $\left\{ \text{corr}(\mathbf{Z}_{it}\hat{\delta}, y_{it}) \right\}^2$.

xtivreg, re

Per Baltagi and Chang (2000), let

$$u = \mu_i + \nu_{it}$$

be the $N \times 1$ vector of combined errors. Then under the assumptions of the random-effects model,

$$E(uu') = \sigma_\nu^2 \text{diag} \left[I_{T_i} - \frac{1}{T_i} \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}_{T_i}' \right] + \text{diag} \left[w_i \frac{1}{T_i} \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}_{T_i}' \right]$$

where

$$\omega_i = T_i \sigma_\mu^2 + \sigma_\nu^2$$

and $\boldsymbol{\iota}_{T_i}$ is a vector of ones of dimension T_i .

Because the variance components are unknown, consistent estimates are required to implement feasible GLS. `xtivreg` offers two choices. The default is a simple extension of the Swamy–Arora method for unbalanced panels.

Let

$$u_{it}^w = \tilde{y}_{it} - \tilde{\mathbf{Z}}_{it} \hat{\delta}_w$$

be the combined residuals from the within estimator. Let \tilde{u}_{it} be the within-transformed u_{it} . Then

$$\hat{\sigma}_\nu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \tilde{u}_{it}^2}{N - n - K + 1}$$

Let

$$u_{it}^b = y_{it} - \mathbf{Z}_{it} \delta_b$$

be the combined residual from the between estimator. Let \bar{u}_{it}^b be the between residuals after they have been passed through the between transform. Then

$$\hat{\sigma}_\mu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \bar{u}_{it}^2 - (n - K) \hat{\sigma}_\nu^2}{N - r}$$

where

$$r = \text{trace} \left\{ \left(\bar{\mathbf{Z}}_i' \bar{\mathbf{Z}}_i \right)^{-1} \bar{\mathbf{Z}}_i' \mathbf{Z}_\mu \mathbf{Z}_\mu' \bar{\mathbf{Z}}_i \right\}$$

where

$$\mathbf{Z}_\mu = \text{diag} \left(\boldsymbol{\iota}_{T_i} \boldsymbol{\iota}_{T_i}' \right)$$

If the `nosa` option is specified, the consistent estimators described in Baltagi and Chang (2000) are used. These are given by

$$\hat{\sigma}_\nu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \tilde{u}_{it}^2}{N - n}$$

and

$$\hat{\sigma}_\mu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \bar{u}_{it}^2 - n\hat{\sigma}_\nu^2}{N}$$

The default Swamy–Arora method contains a degree-of-freedom correction to improve its performance in small samples.

Given estimates of the variance components, $\hat{\sigma}_\nu^2$ and $\hat{\sigma}_\mu^2$, the feasible GLS transform of a variable w is

$$w^* = w_{it} - \hat{\theta}_{it} \bar{w}_i. \quad (4)$$

where

$$\bar{w}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it}$$

$$\hat{\theta}_{it} = 1 - \left(\frac{\hat{\sigma}_\nu^2}{\hat{\omega}_i} \right)^{-\frac{1}{2}}$$

and

$$\hat{\omega}_i = T_i \hat{\sigma}_\mu^2 + \hat{\sigma}_\nu^2$$

Using either estimator of the variance components, `xtivreg` contains two GLS estimators of the random-effects model. These two estimators differ only in how they construct the GLS instruments from the exogenous and instrumental variables contained in $\mathbf{X}_{it} = [\mathbf{X}_{1it} \mathbf{X}_{2it}]$. The default method, G2SLS, which is from Balestra and Varadharajan-Krishnakumar, uses the exogenous variables after they have been passed through the feasible GLS transform. Mathematically, G2SLS uses \mathbf{X}^* for the GLS instruments, where \mathbf{X}^* is constructed by passing each variable in \mathbf{X} through the GLS transform in (4). The G2SLS estimator obtains its coefficient estimates and conventional VCE from an instrumental variable regression of y_{it}^* on \mathbf{Z}_{it}^* with instruments \mathbf{X}_{it}^* .

If the `ec2sls` option is specified, `xtivreg` performs Baltagi's EC2SLS. In EC2SLS, the instruments are $\tilde{\mathbf{X}}_{it}$ and $\bar{\mathbf{X}}_{it}$, where $\tilde{\mathbf{X}}_{it}$ is constructed by each of the variables in \mathbf{X}_{it} throughout the GLS transform in (4), and $\bar{\mathbf{X}}_{it}$ is made of the group means of each variable in \mathbf{X}_{it} . The EC2SLS estimator obtains its coefficient estimates and its VCE from an instrumental variables regression of y_{it}^* on \mathbf{Z}_{it}^* with instruments $\tilde{\mathbf{X}}_{it}$ and $\bar{\mathbf{X}}_{it}$.

Baltagi and Li (1992) show that although the G2SLS instruments are a subset of those in EC2SLS, the extra instruments in EC2SLS are redundant in the sense of White (2001). Given the extra computational cost, G2SLS is the default.

The standard deviation of $\mu_i + \nu_{it}$ is calculated as $\sqrt{\hat{\sigma}_\mu^2 + \hat{\sigma}_\nu^2}$.

R^2 between is reported as $\left\{ \text{corr}(\overline{\mathbf{Z}}_i \widehat{\boldsymbol{\delta}}, \overline{y}_i) \right\}^2$.

R^2 within is reported as $\left[\text{corr}\{(\mathbf{Z}_{it} - \overline{\mathbf{Z}}_i) \widehat{\boldsymbol{\delta}}, y_{it} - \overline{y}_i\} \right]^2$.

R^2 overall is reported as $\left\{ \text{corr}(\mathbf{Z}_{it} \widehat{\boldsymbol{\delta}}, y_{it}) \right\}^2$.

Acknowledgment

We thank Mead Over of the Center for Global Development, who wrote an early implementation of `xtivreg`.

References

- Amemiya, T. 1971. The estimation of the variances in a variance-components model. *International Economic Review* 12: 1–13.
- Anderson, T. W., and C. Hsiao. 1981. Estimation of dynamic models with error components. *Journal of the American Statistical Association* 76: 598–606.
- Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.
- Balestra, P., and J. Varadharajan-Krishnakumar. 1987. Full information estimations of a system of simultaneous equations with error component structure. *Econometric Theory* 3: 223–246.
- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Baltagi, B. H., and Y.-J. Chang. 1994. Incomplete panels: A comparative study of alternative estimators for the unbalanced one-way error component regression model. *Journal of Econometrics* 62: 67–89.
- . 2000. Simultaneous equations with incomplete panels. *Econometric Theory* 16: 269–279.
- Baltagi, B. H., and Q. Li. 1992. A note on the estimation of simultaneous equations with error components. *Econometric Theory* 8: 113–119.
- Hsiao, C. 2003. *Analysis of Panel Data*. 2nd ed. New York: Cambridge University Press.
- Layard, R., and S. J. Nickell. 1986. Unemployment in Britain. *Economica* 53: S121–S169.
- Mundlak, Y. 1978. On the pooling of time series and cross section data. *Econometrica* 46: 69–85.
- Swamy, P. A. V. B., and S. S. Arora. 1972. The exact finite sample properties of the estimators of coefficients in the error components regression models. *Econometrica* 40: 261–275.
- White, H. L., Jr. 2001. *Asymptotic Theory for Econometricians*. Rev. ed. New York: Academic Press.
- Wooldridge, J. M. 1990. A note on the Lagrange multiplier and F-statistics for two stage least squares regressions. *Economics Letters* 34: 151–155.

Also see

- [XT] **xtivreg postestimation** — Postestimation tools for `xtivreg`
- [XT] **xtset** — Declare data to be panel data
- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [XT] **xhtaylor** — Hausman–Taylor estimator for error-components models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [R] **ivregress** — Single-equation instrumental-variables regression
- [U] **20 Estimation and postestimation commands**

Description

The following postestimation commands are available after `xtivreg`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

For all but the first-differenced estimator

```
predict [type] newvar [if] [in] [ , statistic ]
```

First-differenced estimator

```
predict [type] newvar [if] [in] [ , FD_statistic ]
```


<i>statistic</i>	Description
Main	
xb	$\mathbf{Z}_{it}\widehat{\boldsymbol{\delta}}$, fitted values; the default
ue	$\widehat{\mu}_i + \widehat{\nu}_{it}$, the combined residual
* xbu	$\mathbf{Z}_{it}\widehat{\boldsymbol{\delta}} + \widehat{\mu}_i$, prediction including effect
* u	$\widehat{\mu}_i$, the fixed- or random-error component
* e	$\widehat{\nu}_{it}$, the overall error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

<i>FD_statistic</i>	Description
Main	
xb	$\mathbf{x}_j\mathbf{b}$, fitted values for the first-differenced model; the default
e	$e_{it} - e_{it-1}$, the first-differenced overall error component

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- xb, the default, calculates the linear prediction, that is, $\mathbf{Z}_{it}\widehat{\boldsymbol{\delta}}$.
- ue calculates the prediction of $\widehat{\mu}_i + \widehat{\nu}_{it}$. This is not available after the first-differenced model.
- xbu calculates the prediction of $\mathbf{Z}_{it}\widehat{\boldsymbol{\delta}} + \widehat{\mu}_i$, the prediction including the fixed or random component. This is not available after the first-differenced model.
- u calculates the prediction of $\widehat{\mu}_i$, the estimated fixed or random effect. This is not available after the first-differenced model.
- e calculates the prediction of $\widehat{\nu}_{it}$.

Also see

[XT] [xtivreg](#) — Instrumental variables and two-stage least squares for panel-data models
[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description
Options for graph by panel	Options for overlaid panels	Remarks and examples
Also see		

Syntax

Graph by panel

```
xtline varlist [ if ] [ in ] [ , panel_options ]
```

Overlaid panels

```
xtline varname [ if ] [ in ], overlay [ overlaid_options ]
```

panel_options	Description
Main	
i(varname _i)	use varname _i as the panel ID variable
t(varname _t)	use varname _t as the time variable
Plot	
cline_options	affect rendition of the plotted points connected by lines
Add plots	
addplot(plot)	add other plots to the generated graph
Y axis, Time axis, Titles, Legend, Overall	
twoway_options	any options other than by() documented in [G-3] twoway_options
byopts(byopts)	affect appearance of the combined graph

overlaid_options	Description
Main	
overlay	overlay each panel on the same graph
i(varname _i)	use varname _i as the panel ID variable
t(varname _t)	use varname _t as the time variable
Plots	
plot#opts(cline_options)	affect rendition of the # panel line
Add plots	
addplot(plot)	add other plots to the generated graph
Y axis, Time axis, Titles, Legend, Overall	
twoway_options	any options other than by() documented in [G-3] twoway_options

A panel variable and a time variable must be specified. Use xtset (see [XT] xtset) or specify the i() and t() options. The t() option allows noninteger values for the time variable, whereas xtset does not.

Menu

Statistics > Longitudinal/panel data > Line plots

Description

`xtline` draws line plots for panel data.

Options for graph by panel

Main

`i(varnamei)` and `t(varnamet)` override the panel settings from `xtset`; see [XT] [xtset](#). `varnamei` is allowed to be a string variable. `varnamet` can take on noninteger values and have repeated values within panel. That is to say, it can be any numeric variable that you would like to specify for the *x*-dimension of the graph. It is an error to specify `i()` without `t()` and vice versa.

Plot

`cline_options` affect the rendition of the plotted points connected by lines; see [G-3] [cline_options](#).

Add plots

`addplot(plot)` provides a way to add other plots to the generated graph; see [G-3] [addplot_option](#).

Y axis, Time axis, Titles, Legend, Overall

`twoway_options` are any of the options documented in [G-3] [twoway_options](#), excluding `by()`. These include options for titling the graph (see [G-3] [title_options](#)) and for saving the graph to disk (see [G-3] [saving_option](#)).

`byopts(byopts)` allows all the options documented in [G-3] [by_option](#). These options affect the appearance of the by-graph. `byopts()` may not be combined with `overlay`.

Options for overlaid panels

Main

`overlay` causes the plot from each panel to be overlaid on the same graph. The default is to generate plots by panel. This option may not be combined with `byopts()` or be specified when there are multiple variables in `varlist`.

`i(varnamei)` and `t(varnamet)` override the panel settings from `xtset`; see [XT] [xtset](#). `varnamei` is allowed to be a string variable. `varnamet` can take on noninteger values and have repeated values within panel. That is to say, it can be any numeric variable that you would like to specify for the *x*-dimension of the graph. It is an error to specify `i()` without `t()` and vice versa.

Plots

`plot#opts(cline_options)` affect the rendition of the *#*th panel (in sorted order). The `cline_options` can affect whether and how the points are connected; see [G-3] [cline_options](#).

Add plots

`addplot(plot)` provides a way to add other plots to the generated graph; see [G-3] [addplot_option](#).

Y axis, Time axis, Titles, Legend, Overall

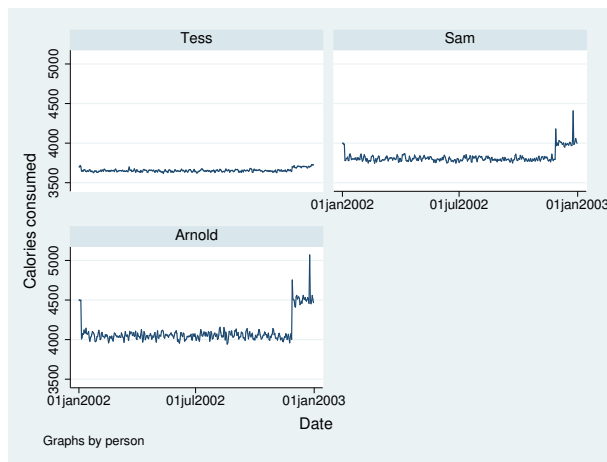
twoway_options are any of the options documented in [G-3] *twoway_options*, excluding `by()`. These include options for titling the graph (see [G-3] *title_options*) and for saving the graph to disk (see [G-3] *saving_option*).

Remarks and examples

► Example 1

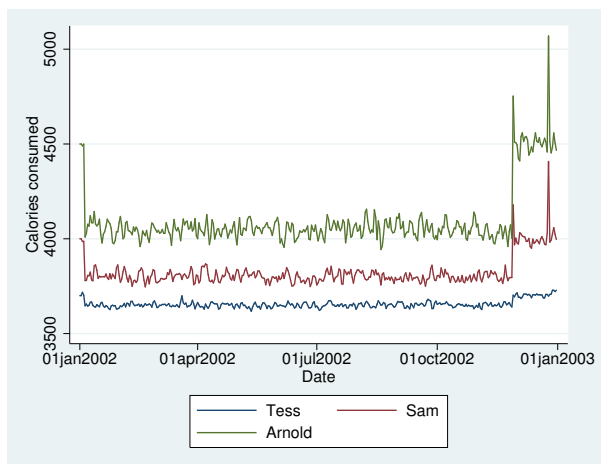
Suppose that Tess, Sam, and Arnold kept a calorie log for an entire calendar year. At the end of the year, if they pooled their data together, they would have a dataset (for example, `xtline1.dta`) that contains the number of calories each of them consumed for 365 days. They could then use `xtset` to identify the date variable and treat each person as a panel and use `xtline` to plot the calories versus time for each person separately.

```
. use http://www.stata-press.com/data/r13/xtline1
. xtset person day
    panel variable:  person (strongly balanced)
    time variable:  day, 01jan2002 to 31dec2002
                  delta: 1 day
. xtline calories, tlabel(#3)
```



Specify the `overlay` option so that the values are plotted on the same graph to provide a better comparison among Tess, Sam, and Arnold.


```
. xtline calories, overlay
```



Also see

[XT] **xtset** — Declare data to be panel data

[G-2] **graph twoway** — Twoway graphs

[TS] **tsline** — Plot time-series data

Syntax	Menu	Description
Options for RE model	Options for FE model	Options for PA model
Remarks and examples	Stored results	Methods and formulas
References	Also see	

Syntax

Random-effects (RE) model

```
xtlogit depvar [indepvars] [if] [in] [weight] [ , re RE_options ]
```

Conditional fixed-effects (FE) model

```
xtlogit depvar [indepvars] [if] [in] [weight] , fe [FE_options ]
```

Population-averaged (PA) model

```
xtlogit depvar [indepvars] [if] [in] [weight] , pa [PA_options ]
```


<i>RE_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
<u>asis</u>	retain perfect predictor variables
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>or</u>	report odds ratios
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<i>maximize_options</i>	control the maximization process; seldom used
<u>nodisplay</u>	suppress display of header and coefficients
<u>coeflegend</u>	display legend instead of statistics

<i>FE_options</i>	Description
Model	
<code>fe</code>	use fixed-effects estimator
<code>offset(<i>varname</i>)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>constraints(<i>constraints</i>)</code>	apply specified linear constraints
<code>collinear</code>	keep collinear variables
SE	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>oim</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>or</code>	report odds ratios
<code>noskip</code>	perform overall model test as a likelihood-ratio test
<code>nocnsreport</code>	do not display constraints
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<code>maximize_options</code>	control the maximization process; seldom used
<code>nodisplay</code>	suppress display of header and coefficients
<code>coeflegend</code>	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>asis</u>	retain perfect predictor variables
Correlation	
<u>corr</u> (<i>correlation</i>)	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>conventional</u> , <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default N
<u>scale</u> (<i>parm</i>)	overrides the default scale parameter; <i>parm</i> may be <code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code>
Reporting	
<u>level</u> (<i>#</i>)	set confidence level; default is <code>level(95)</code>
<u>or</u>	report odds ratios
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<u>optimize_options</u>	control the optimization process; seldom used
<u>nodisplay</u>	do not display the header and coefficients
<u>coeflegend</u>	display legend instead of statistics
<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> <i>#</i>	autoregressive of order <i>#</i>
<u>stationary</u> <i>#</i>	stationary of order <i>#</i>
<u>nonstationary</u> <i>#</i>	nonstationary of order <i>#</i>

A panel variable must be specified. For `xtlogit`, `pa`, correlation structures other than exchangeable and independent require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

`indepvars` may contain factor variables; see [U] [11.4.3 Factor variables](#).

`depvar` and `indepvars` may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).

`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#). `fp` is allowed for the random-effects and fixed-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).

`iweights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `iweights` are allowed for the fixed-effects and random-effects models; see [U] [11.1.6 weight](#). Weights must be constant within panel.

`nodisplay` and `coeflegend` do not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Binary outcomes > Logistic regression (FE, RE, PA)

Description

`xtlogit` fits random-effects, conditional fixed-effects, and population-averaged logit models. Whenever we refer to a fixed-effects model, we mean the conditional fixed-effects model. `depvar` equal to nonzero and nonmissing (typically `depvar` equal to one) indicates a positive outcome, whereas `depvar` equal to zero indicates a negative outcome.

By default, the population-averaged model is an equal-correlation model; `xtlogit`, `pa` assumes `corr(exchangeable)`. See [XT] [xtgee](#) for information on how to fit other population-averaged models.

See [R] [logistic](#) for a list of related estimation commands.

Options for RE model

Model

`noconstant`; see [R] [estimation options](#).

`re` requests the random-effects estimator, which is the default.

`offset(varname)` `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtlogit](#), [re](#) and [the robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`; see [R] [estimation options](#).

or reports the estimated coefficients transformed to odds ratios, that is, e^b rather than b . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. or may be specified at estimation or when replaying previously estimated results.

noskip; see [R] [estimation options](#).

nocnsreport; see [R] [estimation options](#).

display_options: [noomitted](#), [vsquish](#), [noemptycells](#), [baselevels](#), [allbaselevels](#), [nofvlabel](#), [fvwrap\(#\)](#), [fvwrapon\(style\)](#), [cformat\(%fmt\)](#), [pformat\(%fmt\)](#), [sformat\(%fmt\)](#), and [nolstretch](#); see [R] [estimation options](#).

Integration

[intmethod\(intmethod\)](#), [intpoints\(#\)](#); see [R] [estimation options](#).

Maximization

maximize_options: [difficult](#), [technique\(algorithm_spec\)](#), [iterate\(#\)](#), [\[no\]log](#), [trace](#), [gradient](#), [showstep](#), [hessian](#), [showtolerance](#), [tolerance\(#\)](#), [ltolerance\(#\)](#), [nrtolerance\(#\)](#), [nonrtolerance](#), and [from\(init_specs\)](#); see [R] [maximize](#). These options are seldom used.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] [estimation options](#).

Options for FE model

Model

`fe` requests the fixed-effects estimator.

[offset\(varname\)](#), [constraints\(constraints\)](#), [collinear](#); see [R] [estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Reporting

[level\(#\)](#); see [R] [estimation options](#).

or reports the estimated coefficients transformed to odds ratios, that is, e^b rather than b . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. or may be specified at estimation or when replaying previously estimated results.

noskip; see [R] [estimation options](#).

nocnsreport; see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fnt)`, `pformat(%fnt)`, `sformat(%fnt)`, and `nolstretch`; see [R] [estimation options](#).

Maximization

maximize_options: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator.

`offset(varname)`; see [R] [estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp, scale(x2 | dev | phi | #)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`or` reports the estimated coefficients transformed to odds ratios, that is, e^b rather than b . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

display_options: `noomit`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Optimization

optimize_options control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtlogit` is a convenience command if you want the population-averaged model. Typing

```
. xtlogit ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(logit) corr(exchangeable)
```

It is also a convenience command if you want the fixed-effects model. Typing

```
. xtlogit ..., fe ...
```

is equivalent to typing

```
. clogit ..., group(varname_i) ...
```

See also [XT] [xtgee](#) and [R] [clogit](#) for information about `xtlogit`.

By default or when `re` is specified, `xtlogit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = P(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, ν_i are i.i.d., $N(0, \sigma_\nu^2)$, and $P(z) = \{1 + \exp(-z)\}^{-1}$.

Underlying this model is the variance components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} > 0$$

where ϵ_{it} are i.i.d. logistic distributed with mean zero and variance $\sigma_\epsilon^2 = \pi^2/3$, independently of ν_i .

► Example 1

We are studying unionization of women in the United States and are using the union dataset; see [XT] xt. We wish to fit a random-effects model of union membership:

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)
. xtlogit union age grade not_smsa south##c.year
(output omitted)

Random-effects logistic regression      Number of obs      =      26200
Group variable: idcode                 Number of groups    =      4434
Random effects u_i ~ Gaussian          Obs per group: min =           1
                                      avg =          5.9
                                      max =          12

Integration method: mvaghermite        Integration points =          12
Wald chi2(6) =          227.46
Log likelihood = -10540.274             Prob > chi2         =          0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0156732	.0149895	1.05	0.296	-.0137056	.045052
grade	.0870851	.0176476	4.93	0.000	.0524965	.1216738
not_smsa	-.2511884	.0823508	-3.05	0.002	-.4125929	-.0897839
1.south	-2.839112	.6413116	-4.43	0.000	-4.096059	-1.582164
year	-.0068604	.0156575	-0.44	0.661	-.0375486	.0238277
south#c.year						
1	.0238506	.0079732	2.99	0.003	.0082235	.0394777
_cons	-3.009365	.8414963	-3.58	0.000	-4.658667	-1.360062
/lnsig2u	1.749366	.0470017			1.657245	1.841488
sigma_u	2.398116	.0563577			2.290162	2.511158
rho	.6361098	.0108797			.6145307	.6571548

Likelihood-ratio test of rho=0: chibar2(01) = 6004.43 Prob >= chibar2 = 0.000

The output includes the additional panel-level variance component. This is parameterized as the log of the variance $\ln(\sigma_\nu^2)$ (labeled `lnsig2u` in the output). The standard deviation σ_ν is also included in the output and labeled `sigma_u` together with ρ (labeled `rho`),

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + \sigma_\epsilon^2}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When `rho` is zero, the panel-level variance component is unimportant, and the panel estimator is no different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (logit) with the panel estimator.

As an alternative to the random-effects specification, we might want to fit an equal-correlation logit model:


```
. xtlogit union age grade not_smsa south##c.year, pa
Iteration 1: tolerance = .1487877
Iteration 2: tolerance = .00949342
Iteration 3: tolerance = .00040606
Iteration 4: tolerance = .00001602
Iteration 5: tolerance = 6.628e-07

GEE population-averaged model
Group variable:          idcode      Number of obs      =      26200
Link:                   logit        Number of groups   =      4434
Family:                 binomial     Obs per group: min =          1
Correlation:            exchangeable          avg =         5.9
                                      max =         12
                                      Wald chi2(6)      =      235.08
Scale parameter:        1            Prob > chi2        =      0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0165893	.0092229	1.80	0.072	-.0014873	.0346659
grade	.0600669	.0108343	5.54	0.000	.0388321	.0813016
not_smsa	-.1215445	.0483713	-2.51	0.012	-.2163505	-.0267384
1.south	-1.857094	.372967	-4.98	0.000	-2.588096	-1.126092
year	-.0121168	.0095707	-1.27	0.205	-.030875	.0066413
south#c.year						
1	.0160193	.0046076	3.48	0.001	.0069886	.0250501
_cons	-1.39755	.5089508	-2.75	0.006	-2.395075	-.4000247

➤ Example 2

xtlogit with the pa option allows a vce(robust) option, so we can obtain the population-averaged logit estimator with the robust variance calculation by typing

```
. xtlogit union age grade not_smsa south##c.year, pa vce(robust) nolog
GEE population-averaged model
Group variable:          idcode      Number of obs      =      26200
Link:                   logit        Number of groups   =      4434
Family:                 binomial     Obs per group: min =          1
Correlation:            exchangeable          avg =         5.9
                                      max =         12
                                      Wald chi2(6)      =      154.88
Scale parameter:        1            Prob > chi2        =      0.0000
                                   (Std. Err. adjusted for clustering on idcode)
```

union	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0165893	.008951	1.85	0.064	-.0009543	.0341329
grade	.0600669	.0133193	4.51	0.000	.0339616	.0861722
not_smsa	-.1215445	.0613803	-1.98	0.048	-.2418477	-.0012412
1.south	-1.857094	.5389238	-3.45	0.001	-2.913366	-.8008231
year	-.0121168	.0096998	-1.25	0.212	-.0311282	.0068945
south#c.year						
1	.0160193	.0067217	2.38	0.017	.002845	.0291937
_cons	-1.39755	.5603767	-2.49	0.013	-2.495868	-.2992317

These standard errors are somewhat larger than those obtained without the vce(robust) option.

Finally, we can also fit a fixed-effects model to these data (see also [R] [clogit](#) for details):

```
. xtlogit union age grade not_smsa south##c.year, fe
note: multiple positive outcomes within groups encountered.
note: 2744 groups (14165 obs) dropped because of all positive or
      all negative outcomes.

Iteration 0:  log likelihood = -4516.5881
Iteration 1:  log likelihood = -4510.8906
Iteration 2:  log likelihood = -4510.888
Iteration 3:  log likelihood = -4510.888

Conditional fixed-effects logistic regression
Group variable: idcode

Number of obs      =      12035
Number of groups   =      1690
Obs per group: min =         2
                  avg =        7.1
                  max =        12

LR chi2(6)         =       78.60
Prob > chi2        =       0.0000

Log likelihood     = -4510.888
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0710973	.0960536	0.74	0.459	-.1171643	.2593589
grade	.0816111	.0419074	1.95	0.051	-.0005259	.163748
not_smsa	.0224809	.1131786	0.20	0.843	-.199345	.2443069
1.south	-2.856488	.6765694	-4.22	0.000	-4.182539	-1.530436
year	-.0636853	.0967747	-0.66	0.510	-.2533602	.1259896
south#c.year						
1	.0264136	.0083216	3.17	0.002	.0101036	.0427235

◀

□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] [quadchk](#) for details and [XT] [xtprobit](#) for an example.

Because the `xtlogit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

□

Stored results

`xtlogit`, `re` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	ρ
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtlogit`, `fe` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_drop)</code>	number of observations dropped because of all positive or all negative outcomes
<code>e(N_group_drop)</code>	number of groups dropped because of all positive or all negative outcomes
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(r2_p)</code>	pseudo R -squared
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(chi2)</code>	χ^2
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>clogit</code>
<code>e(cmd2)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>fe</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	LR; type of model χ^2 test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(group)</code>	name of <code>group()</code> variable
<code>e(multiple)</code>	multiple if multiple positive outcomes within groups
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtlogit`, `pa` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(df_pear)</code>	degrees of freedom for Pearson χ^2
<code>e(chi2_dev)</code>	χ^2 test of deviance
<code>e(chi2_dis)</code>	χ^2 test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>binomial</code>
<code>e(link)</code>	<code>logit</code> ; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code> ; scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<i>vctype</i> specified in <code>vce()</code>
<code>e(vctype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

xtlogit reports the population-averaged results obtained using xtgee, family(binomial) link(logit) to obtain estimates. The fixed-effects results are obtained using clogit. See [XT] xtgee and [R] clogit for details on the methods and formulas.

If we assume a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i ,

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} \frac{1}{1 + \exp(-z)} & \text{if } y \neq 0 \\ \frac{1}{1 + \exp(z)} & \text{otherwise} \end{cases}$$

The panel-level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, with the definition of $g(y_{it}, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right]$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of $1e-6$; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where $\rho = \sigma_\nu^2/(\sigma_\nu^2 + 1)$:

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

xtlogit, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Allison, P. D. 2009. *Fixed Effects Regression Models*. Newbury Park, CA: Sage.
- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Conway, M. R. 1990. A random effects model for binary data. *Biometrics* 46: 317–328.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Neuhaus, J. M., J. D. Kalbfleisch, and W. W. Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59: 25–35.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Twisk, J. W. R. 2013. *Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide*. 2nd ed. Cambridge: Cambridge University Press.
- Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtlogit postestimation** — Postestimation tools for xtlogit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtcloglog** — Random-effects and population-averaged cloglog models
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **melogit** — Multilevel mixed-effects logistic regression
- [ME] **meqrlogit** — Multilevel mixed-effects logistic regression (QR decomposition)
- [MI] **estimation** — Estimation commands for use with mi estimate
- [R] **clogit** — Conditional (fixed-effects) logistic regression
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **logit** — Logistic regression, reporting coefficients
- [U] **20 Estimation and postestimation commands**

[Description](#)
Remarks and examples

[Syntax for predict](#)
Also see

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtlogit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code> ³	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtlogit`, `pa`.
² `forecast` is not appropriate with `mi` estimation results or after `xtlogit`, `fe`.
³ The default prediction statistic for `xtlogit`, `fe`, `pu1`, cannot be correctly handled by `margins`; however, `margins` can be used after `xtlogit`, `fe` with the `predict(pu0)` option or the `predict(xb)` option.

Syntax for predict

Random-effects model

```
predict [type] newvar [if] [in] [ , RE_statistic nooffset ]
```

Fixed-effects model

```
predict [type] newvar [if] [in] [ , FE_statistic nooffset ]
```

Population-averaged model

```
predict [type] newvar [if] [in] [ , PA_statistic nooffset ]
```

RE_statistic	Description
Main	
xb	linear prediction; the default
pu0	probability of a positive outcome assuming that the random effect is zero
stdp	standard error of the linear prediction
FE_statistic	Description
Main	
pc1	predicted probability of a positive outcome conditional on one positive outcome within group; the default
pu0	probability of a positive outcome assuming that the fixed effect is zero
xb	linear prediction
stdp	standard error of the linear prediction
PA_statistic	Description
Main	
mu	predicted probability of <i>depvar</i> ; considers the <code>offset()</code>
rate	predicted probability of <i>depvar</i>
xb	linear prediction
stdp	standard error of the linear prediction
score	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

The predicted probability for the fixed-effects model is conditional on there being only one outcome per group. See [\[R\] clogit](#) for details.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- `xb` calculates the linear prediction. This is the default for the random-effects model.
- `pc1` calculates the predicted probability of a positive outcome conditional on one positive outcome within group. This is the default for the fixed-effects model.
- `mu` and `rate` both calculate the predicted probability of *depvar*. `mu` takes into account the `offset()`, and `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.
- `pu0` calculates the probability of a positive outcome, assuming that the fixed or random effect for that observation's panel is zero ($\nu = 0$). This may not be similar to the proportion of observed outcomes in the group.
- `stdp` calculates the standard error of the linear prediction.
- `score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\beta) / \partial (\mathbf{x}_j\beta)$.
- `nooffset` is relevant only if you specified `offset(varname)` for `xtlogit`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [XT] `xtlogit`, we fit a random-effects model of union status on the person's age and level of schooling, whether she lived in an urban area, and whether she lived in the south. In fact, we included the full interaction between `south` and `year` to capture both the overall effect of residing in the south and a separate time-trend for southerners. To test whether residing in the south affects union status, we must determine whether `1.south` and `south#c.year` are jointly significant. First, we refit our model, store the estimation results for later use, and use `test` to conduct a Wald test of the joint significance of those two variables' parameters:

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtlogit union age grade not_smsa south##c.year
(output omitted)

. estimates store fullmodel

. test 1.south 1.south#c.year
( 1)  [union]1.south = 0
( 2)  [union]1.south#c.year = 0
      chi2( 2) = 143.93
      Prob > chi2 = 0.0000
```

The test statistic is clearly significant, so we reject the null hypothesis that the coefficients are jointly zero and conclude that living in the south does significantly affect union status.

We can also test our hypothesis with a likelihood-ratio test. Here we fit the model without `south##c.year` and then call `lrtest` to compare this restricted model to the full model:

```
. xtlogit union age grade not_smsa
      (output omitted)
. lrtest fullmodel .
Likelihood-ratio test                LR chi2(3) =    146.55
(Assumption: . nested in fullmodel)  Prob > chi2 =    0.0000
```

These results confirm our finding that living in the south affects union status.

<

Also see

[[XT](#)] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models

[[U](#)] **20 Estimation and postestimation commands**

Syntax	Menu	Description
Options for RE/FE models	Options for PA model	Remarks and examples
Stored results	Methods and formulas	References
Also see		

Syntax

Random-effects (RE) and conditional fixed-effects (FE) overdispersion models

```
xtnbreg depvar [indepvars] [if] [in] [weight] [, [re|fe] RE/FE_options]
```

Population-averaged (PA) model

```
xtnbreg depvar [indepvars] [if] [in] [weight] , pa [PA_options]
```

RE/FE_options	Description
Model	
<u>noconstant</u>	suppress constant term; not available with fe
re	use random-effects estimator; the default
fe	use fixed-effects estimator
<u>exposure</u> (varname)	include ln(varname) in model with coefficient constrained to 1
<u>offset</u> (varname)	include varname in model with coefficient constrained to 1
<u>constraints</u> (constraints)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE	
<u>vce</u> (vcetype)	vcetype may be oim, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>irr</u>	report incidence-rate ratios
noskip	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>exposure</u> (<i>varname</i>)	include ln(<i>varname</i>) in model with coefficient constrained to 1
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
Correlation	
<u>corr</u> (<i>correlation</i>)	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>conventional</u> , <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default N
<u>scale</u> (<i>parm</i>)	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>irr</u>	report incidence-rate ratios
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For `xtnbreg`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

`indepvars` may contain factor variables; see [U] [11.4.3 Factor variables](#).

`devar` and `indepvars` may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).

`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#). `fp` is allowed for the random-effects and fixed-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).

`lweights`, `fwweights`, and `pweights` are allowed for the population-averaged model, and `lweights` are allowed in the random-effects and fixed-effects models; see [U] [11.1.6 weight](#). Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Count outcomes > Negative binomial regression (FE, RE, PA)

Description

`xtnbreg` fits random-effects overdispersion models, conditional fixed-effects overdispersion models, and population-averaged negative binomial models. Here “random effects” and “fixed effects” apply to the distribution of the dispersion parameter, not to the $x\beta$ term in the model. In the random-effects and fixed-effects overdispersion models, the dispersion is the same for all elements in the same group (that is, elements with the same value of the panel variable). In the random-effects model, the dispersion varies randomly from group to group, such that the inverse of one plus the dispersion follows a $\text{Beta}(r, s)$ distribution. In the fixed-effects model, the dispersion parameter in a group can take on any value, because a conditional likelihood is used in which the dispersion parameter drops out of the estimation.

By default, the population-averaged model is an equal-correlation model; `xtnbreg`, `pa` assumes `corr(exchangeable)`. See [XT] [xtgee](#) for information on how to fit other population-averaged models.

Options for RE/FE models

Model

`noconstant`; see [R] [estimation options](#).

`re` requests the random-effects estimator, which is the default.

`fe` requests the conditional fixed-effects estimator.

`exposure(varname)`, `offset(varname)`, `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`irr` reports exponentiated coefficients e^b rather than coefficients b . For the negative binomial model, exponentiated coefficients have the interpretation of incidence-rate ratios.

`noskip`; see [R] [estimation options](#).

`nocnsreport`; see [R] [estimation options](#).

display_options: `noomit`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Maximization

maximize_options: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrntolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtnbreg` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator.

`exposure(varname)`, `offset(varname)`; see [R] [estimation options](#).

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`irr` reports exponentiated coefficients e^b rather than coefficients b . For the negative binomial model, exponentiated coefficients have the interpretation of incidence-rate ratios.

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Optimization

optimize_options control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtnbreg` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtnbreg` is a convenience command if you want the population-averaged model. Typing

```
. xtnbreg ..., ... pa exposure(time)
```

is equivalent to typing

```
. xtgee ..., ... family(nbinomial) link(log) corr(exchangeable) exposure(time)
```

See also [XT] [xtgee](#) for information about `xtnbreg`.

By default, or when `re` is specified, `xtnbreg` fits a maximum-likelihood random-effects overdispersion model.

► Example 1

You have (fictional) data on injury “incidents” incurred among 20 airlines in each of 4 years. (Incidents range from major injuries to exceedingly minor ones.) The government agency in charge of regulating airlines has run an experimental safety training program, and, in each of the years, some airlines have participated and some have not. You now wish to analyze whether the “incident” rate is affected by the program. You choose to estimate using random-effects negative binomial regression, as the dispersion might vary across the airlines for unidentified airline-specific reasons. Your measure of exposure is passenger miles for each airline in each year.


```
. use http://www.stata-press.com/data/r13/airacc
. xtnbreg i_cnt inprog, exposure(pmiles) irr
Fitting negative binomial (constant dispersion) model:
Iteration 0:   log likelihood = -293.57997
Iteration 1:   log likelihood = -293.57997
(output omitted)
Fitting full model:
Iteration 0:   log likelihood = -295.72633
Iteration 1:   log likelihood = -270.49929 (not concave)
(output omitted)
Random-effects negative binomial regression      Number of obs   =      80
Group variable: airline                        Number of groups =      20
Random effects u_i ~ Beta                      Obs per group: min =      4
                                                avg   =     4.0
                                                max   =      4
                                                Wald chi2(1)    =     2.04
Log likelihood = -265.38202                    Prob > chi2     =     0.1532
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.911673	.0590277	-1.43	0.153	.8030206	1.035027
_cons	.0367524	.0407032	-2.98	0.003	.0041936	.3220983
ln(pmiles)	1	(exposure)				
/ln_r	4.794991	.951781			2.929535	6.660448
/ln_s	3.268052	.4709033			2.345098	4.191005
r	120.9033	115.0735			18.71892	780.9007
s	26.26013	12.36598			10.4343	66.08918

Likelihood-ratio test vs. pooled: chibar2(01) = 19.03 Prob>=chibar2 = 0.000

In the output above, the `/ln_r` and `/ln_s` lines refer to $\ln(r)$ and $\ln(s)$, where the inverse of one plus the dispersion is assumed to follow a $\text{Beta}(r, s)$ distribution. The output also includes a likelihood-ratio test, which compares the panel estimator with the pooled estimator (that is, a negative binomial estimator with constant dispersion).

You find that the incidence rate for accidents is not significantly different for participation in the program and that the panel estimator is significantly different from the pooled estimator.

We may alternatively fit a fixed-effects overdispersion model:

```
. xtnbreg i_cnt inprog, exposure(pmiles) irr fe nolog
Conditional FE negative binomial regression      Number of obs      =      80
Group variable: airline                        Number of groups   =      20
                                                Obs per group: min =       4
                                                avg =             4.0
                                                max =             4
                                                Wald chi2(1)      =       2.11
                                                Prob > chi2       =      0.1463

Log likelihood = -174.25143
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.9062669	.0613917	-1.45	0.146	.793587	1.034946
_cons	.0329025	.0331262	-3.39	0.001	.0045734	.2367111
ln(pmiles)	1	(exposure)				



Example 2

We rerun our [previous example](#), but this time we fit a robust equal-correlation population-averaged model:

```
. xtnbreg i_cnt inprog, exposure(pmiles) irr vce(robust) pa
Iteration 1: tolerance = .02499392
Iteration 2: tolerance = .0000482
Iteration 3: tolerance = 2.929e-07
GEE population-averaged model
Group variable:                airline      Number of obs      =      80
Link:                          log          Number of groups   =      20
Family:                        negative binomial(k=1)  Obs per group: min =       4
Correlation:                   exchangeable          avg =             4.0
                                                max =             4
                                                Wald chi2(1)      =       1.28
Scale parameter:                1          Prob > chi2       =      0.2571
                                (Std. Err. adjusted for clustering on airline)
```

i_cnt	Semirobust		z	P> z	[95% Conf. Interval]	
	IRR	Std. Err.				
inprog	.927275	.0617857	-1.13	0.257	.8137513	1.056636
_cons	.0080211	.0004117	-94.02	0.000	.0072535	.00887
ln(pmiles)	1	(exposure)				

We compare this with a pooled estimator with clustered robust-variance estimates:

```
. nbreg i_cnt inprog, exposure(pmiles) irr vce(cluster airline)
Fitting Poisson model:
Iteration 0:   log pseudolikelihood = -293.57997
Iteration 1:   log pseudolikelihood = -293.57997
Fitting constant-only model:
Iteration 0:   log pseudolikelihood = -335.13615
Iteration 1:   log pseudolikelihood = -279.43327
Iteration 2:   log pseudolikelihood = -276.09296
Iteration 3:   log pseudolikelihood = -274.84036
Iteration 4:   log pseudolikelihood = -274.81076
Iteration 5:   log pseudolikelihood = -274.81075
Fitting full model:
Iteration 0:   log pseudolikelihood = -274.56985
Iteration 1:   log pseudolikelihood = -274.55077
Iteration 2:   log pseudolikelihood = -274.55077
Negative binomial regression          Number of obs   =           80
Dispersion      = mean                Wald chi2(1)    =           0.60
Log pseudolikelihood = -274.55077      Prob > chi2     =           0.4369
                                     (Std. Err. adjusted for 20 clusters in airline)
```

i_cnt	IRR	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.9429015	.0713091	-0.78	0.437	.8130032	1.093555
_cons	.007956	.0004237	-90.77	0.000	.0071674	.0088314
ln(pmiles)	1	(exposure)				
/lnalpha	-2.835089	.3351784			-3.492027	-2.178151
alpha	.0587133	.0196794			.0304391	.1132507



Stored results

xtnbreg, re stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(r)</code>	value of r in $\text{Beta}(r, s)$
<code>e(s)</code>	value of s in $\text{Beta}(r, s)$
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	xtnbreg
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	re
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(method)</code>	estimation method
<code>e(distrib)</code>	Beta; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

xtnbreg, **fe** stores the following in **e()**:

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(k)	number of parameters
e(k_eq)	number of equations in e(b)
e(k_eq_model)	number of equations in overall model test
e(k_dv)	number of dependent variables
e(df_m)	model degrees of freedom
e(r2_p)	pseudo <i>R</i> -squared
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(chi2)	χ^2
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(p)	significance
e(rank)	rank of e(V)
e(ic)	number of iterations
e(rc)	return code
e(converged)	1 if converged, 0 otherwise

Macros

e(cmd)	xtnbreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	fe
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(offset)	linear offset variable
e(chi2type)	LR; type of model χ^2 test
e(vce)	<i>vcetype</i> specified in vce()
e(vcetype)	title used to label Std. Err.
e(method)	requested estimation method
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
------------------	-------------------------

xtnbreg, pa stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(chi2)	χ^2
e(p)	significance
e(df_pear)	degrees of freedom for Pearson χ^2
e(chi2_dev)	χ^2 test of deviance
e(chi2_dis)	χ^2 test of deviance dispersion
e(deviance)	deviance
e(dispers)	deviance dispersion
e(phi)	scale parameter
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(rank)	rank of e(V)
e(tol)	target tolerance
e(dif)	achieved tolerance
e(rc)	return code

Macros

e(cmd)	xtgee
e(cmd2)	xtnbreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(model)	pa
e(family)	negative binomial($k=1$)
e(link)	log; link function
e(corr)	correlation structure
e(scale)	x2, dev, phi, or #, scale parameter
e(wtype)	weight type
e(wexp)	weight expression
e(offset)	linear offset variable
e(chi2type)	Wald; type of model χ^2 test
e(vce)	vcetype specified in vce()
e(vcetype)	title used to label Std. Err.
e(nmp)	nmp, if specified
e(nbalpha)	α
e(properties)	b V
e(predict)	program used to implement predict
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(R)	estimated working correlation matrix
e(V)	variance-covariance matrix of the estimators
e(V_modelbased)	model-based variance

Functions

e(sample)	marks estimation sample
-----------	-------------------------

Methods and formulas

`xtnbreg`, `pa` reports the population-averaged results obtained by using `xtgee`, `family(nbinomial)` `link(log)` to obtain estimates. See [XT] `xtgee` for details on the methods and formulas.

For the random-effects and fixed-effects overdispersion models, let y_{it} be the count for the t th observation in the i th group. We begin with the model $y_{it} \mid \gamma_{it} \sim \text{Poisson}(\gamma_{it})$, where $\gamma_{it} \mid \delta_i \sim \text{gamma}(\lambda_{it}, \delta_i)$ with $\lambda_{it} = \exp(\mathbf{x}_{it}\beta + \text{offset}_{it})$ and δ_i is the dispersion parameter. This yields the model

$$\Pr(Y_{it} = y_{it} \mid \mathbf{x}_{it}, \delta_i) = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left(\frac{1}{1 + \delta_i} \right)^{\lambda_{it}} \left(\frac{\delta_i}{1 + \delta_i} \right)^{y_{it}}$$

(See Hausman, Hall, and Griliches [1984, eq. 3.1, 922]; our δ is the inverse of their δ .) Looking at within-panel effects only, we find that this specification yields a negative binomial model for the i th group with dispersion (variance divided by the mean) equal to $1 + \delta_i$, that is, constant dispersion within group. This parameterization of the negative binomial model differs from the default parameterization of `nbreg`, which has dispersion equal to $1 + \alpha \exp(\mathbf{x}\beta + \text{offset})$; see [R] `nbreg`.

For a random-effects overdispersion model, we allow δ_i to vary randomly across groups; namely, we assume that $1/(1 + \delta_i) \sim \text{Beta}(r, s)$. The joint probability of the counts for the i th group is

$$\begin{aligned} \Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} \mid \mathbf{X}_i) &= \int_0^\infty \prod_{t=1}^{n_i} \Pr(Y_{it} = y_{it} \mid \mathbf{x}_{it}, \delta_i) f(\delta_i) d\delta_i \\ &= \frac{\Gamma(r + s)\Gamma(r + \sum_{t=1}^{n_i} \lambda_{it})\Gamma(s + \sum_{t=1}^{n_i} y_{it})}{\Gamma(r)\Gamma(s)\Gamma(r + s + \sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it})} \prod_{t=1}^{n_i} \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \end{aligned}$$

for $\mathbf{X}_i = (\mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i})$ and where f is the probability density function for δ_i . The resulting log likelihood is

$$\begin{aligned} \ln L &= \sum_{i=1}^n w_i \left[\ln \Gamma(r + s) + \ln \Gamma\left(r + \sum_{k=1}^{n_i} \lambda_{ik}\right) + \ln \Gamma\left(s + \sum_{k=1}^{n_i} y_{ik}\right) - \ln \Gamma(r) - \ln \Gamma(s) \right. \\ &\quad \left. - \ln \Gamma\left(r + s + \sum_{k=1}^{n_i} \lambda_{ik} + \sum_{k=1}^{n_i} y_{ik}\right) + \sum_{t=1}^{n_i} \left\{ \ln \Gamma(\lambda_{it} + y_{it}) - \ln \Gamma(\lambda_{it}) - \ln \Gamma(y_{it} + 1) \right\} \right] \end{aligned}$$

where $\lambda_{it} = \exp(\mathbf{x}_{it}\beta + \text{offset}_{it})$ and w_i is the weight for the i th group (Hausman, Hall, and Griliches 1984, eq. 3.5, 927).

For the fixed-effects overdispersion model, we condition the joint probability of the counts for each group on the sum of the counts for the group (that is, the observed $\sum_{t=1}^{n_i} y_{it}$). This yields

$$\begin{aligned} \Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} \mid \mathbf{X}_i, \sum_{t=1}^{n_i} Y_{it} = \sum_{t=1}^{n_i} y_{it}) \\ = \frac{\Gamma(\sum_{t=1}^{n_i} \lambda_{it})\Gamma(\sum_{t=1}^{n_i} y_{it} + 1)}{\Gamma(\sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it})} \prod_{t=1}^{n_i} \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \end{aligned}$$

The conditional log likelihood is

$$\ln L = \sum_{i=1}^n w_i \left[\ln \Gamma \left(\sum_{t=1}^{n_i} \lambda_{it} \right) + \ln \Gamma \left(\sum_{t=1}^{n_i} y_{it} + 1 \right) - \ln \Gamma \left(\sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it} \right) \right. \\ \left. + \sum_{t=1}^{n_i} \left\{ \ln \Gamma(\lambda_{it} + y_{it}) - \ln \Gamma(\lambda_{it}) - \ln \Gamma(y_{it} + 1) \right\} \right]$$

See [Hausman, Hall, and Griliches \(1984\)](#) for a more thorough development of the random-effects and fixed-effects models. Also see [Cameron and Trivedi \(2013\)](#) for a good textbook treatment of this model.

References

- Cameron, A. C., and P. K. Trivedi. 2013. *Regression Analysis of Count Data*. 2nd ed. New York: Cambridge University Press.
- Guimarães, P. 2005. [A simple approach to fit the beta-binomial model](#). *Stata Journal* 5: 385–394.
- Hausman, J. A., B. H. Hall, and Z. Griliches. 1984. Econometric models for count data with an application to the patents–R & D relationship. *Econometrica* 52: 909–938.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.

Also see

- [XT] [xtnbreg postestimation](#) — Postestimation tools for xtnbreg
- [XT] [xtgee](#) — Fit population-averaged panel-data models by using GEE
- [XT] [xtpoisson](#) — Fixed-effects, random-effects, and population-averaged Poisson models
- [XT] [xtset](#) — Declare data to be panel data
- [ME] [menbreg](#) — Multilevel mixed-effects negative binomial regression
- [MI] [estimation](#) — Estimation commands for use with mi estimate
- [R] [nbreg](#) — Negative binomial regression
- [U] [20 Estimation and postestimation commands](#)

[Description](#)
Methods and formulas

[Syntax for predict](#)
Also see

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtnbreg`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtnbreg, pa`.
² `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

Random-effects (RE) and conditional fixed-effects (FE) overdispersion models

```
predict [type] newvar [if] [in] [, RE/FE_statistic nooffset]
```

Population-averaged (PA) model

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```


<i>RE/FE_statistic</i>	Description
Main	
xb	linear prediction; the default
stdp	standard error of the linear prediction
nu0	predicted number of events; assumes fixed or random effect is zero
iru0	predicted incidence rate; assumes fixed or random effect is zero
pr0(<i>n</i>)	probability $\Pr(y_j = n)$ assuming the random effect is zero; only allowed after xtnbreg, re
pr0(<i>a, b</i>)	probability $\Pr(a \leq y_j \leq b)$ assuming the random effect is zero; only allowed after xtnbreg, re

<i>PA_statistic</i>	Description
Main	
mu	predicted number of events; considers the offset() ; the default
rate	predicted number of events
xb	linear prediction
stdp	standard error of the linear prediction
score	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type **predict ... if e(sample) ...** if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb calculates the linear prediction. This is the default for the random-effects and fixed-effects models. **mu** and **rate** both calculate the predicted number of events. **mu** takes into account the **offset()**, and **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify **offset()**. **mu** is the default for the population-averaged model.

stdp calculates the standard error of the linear prediction.

nu0 calculates the predicted number of events, assuming a zero random or fixed effect.

iru0 calculates the predicted incidence rate, assuming a zero random or fixed effect.

pr0(*n*) calculates the probability $\Pr(y_j = n)$ assuming the random effect is zero, where *n* is a nonnegative integer that may be specified as a number or a variable (only allowed after **xtnbreg, re**).

pr0(*a, b*) calculates the probability $\Pr(a \leq y_j \leq b)$ assuming the random effect is zero, where *a* and *b* are nonnegative integers that may be specified as numbers or variables (only allowed after **xtnbreg, re**);

b missing ($b \geq .$) means $+\infty$;

`pr0(20,.)` calculates $\Pr(y_j \geq 20)$;

`pr0(20, b)` calculates $\Pr(y_j \geq 20)$ in observations for which $b \geq .$ and calculates $\Pr(20 \leq y_j \leq b)$ elsewhere.

`pr0(., b)` produces a syntax error. A missing value in an observation on the variable a causes a missing value in that observation for `pr0(a , b)`.

`score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\boldsymbol{\beta}) / \partial(\mathbf{x}_j\boldsymbol{\beta})$.

`nooffset` is relevant only if you specified `offset(varname)` for `xtnbreg`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\boldsymbol{\beta}$ rather than $\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it}$.

Methods and formulas

The probabilities calculated using the `pr0(n)` option are the probability $\Pr(y_{it} = n)$ for a RE model assuming the random effect is zero. A negative binomial model is an overdispersed Poisson model, and the nominal overdispersion can be calculated as $\delta = s/(r - 1)$, where r and s are as given in the estimation results. Define $\mu_{it} = \exp(\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it})$. Then the probabilities in `pr0(n)` are calculated as the probability that $y_{it} = n$, where y_{it} has a negative binomial distribution with mean $\delta\mu_{it}$ and variance $\delta(1 + \delta)\mu_{it}$.

Also see

[XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models

[U] **20 Estimation and postestimation commands**

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtologit devar [indepvars] [if] [in] [, options]
```

<i>options</i>	Description
Model	
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>or</u>	report odds ratios
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <code>intpoints(12)</code>
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>startgrid</u> (<i>numlist</i>)	improve starting value of the random-intercept parameter by performing a grid search
<u>nodisplay</u>	suppress display of header and coefficients
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; see [XT] [xtset](#).
indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).
devar and *indepvars* may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).
by, *fp*, and *statsby* are allowed; see [U] [11.1.10 Prefix commands](#).
`startgrid()`, `nodisplay`, and `coeflegend` do not appear in the dialog box.
See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Ordinal outcomes > Logistic regression (RE)

Description

`xtlogit` fits random-effects ordered logistic models. The actual values taken on by the dependent variable are irrelevant, although larger values are assumed to correspond to “higher” outcomes. The conditional distribution of the dependent variable given the random effects is assumed to be multinomial with success probability determined by the logistic cumulative distribution function.

Options

Model

`offset(varname)`, `constraints(constraints)`, `collinear`; see [\[R\] estimation options](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtlogit and the robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`; see [\[R\] estimation options](#).

`or` reports the estimated coefficients transformed to odds ratios, that is, e^b rather than b . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

`noskip`, `nocnsreport`; see [\[R\] estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [\[R\] estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrntolerance`, and `from(init_specs)`; see [\[R\] maximize](#). These options are seldom used.

The following options are available with `xtologit` but are not shown in the dialog box:

`startgrid(numlist)` performs a grid search to improve the starting value of the random-intercept parameter. No grid search is performed by default unless the starting value is found to not be feasible; in this case, `xtologit` runs `startgrid(0.1 1 10)` and chooses the value that works best. You may already be using a default form of `startgrid()` without knowing it. If you see `xtologit` displaying Grid node 1, Grid node 2, ... following Grid node 0 in the iteration log, that is `xtologit` doing a default search because the original starting value was not feasible.

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtologit` fits random-effects ordered logistic models. Ordered logistic models are used to estimate relationships between an ordinal dependent variable and a set of independent variables. An *ordinal* variable is a variable that is categorical and ordered, for instance, “poor”, “good”, and “excellent”, which might indicate a person’s current health status or the repair record of a car. If there are only two outcomes, see [XT] [xtlogit](#), [XT] [xtprobit](#), and [XT] [xtcloglog](#). This entry is concerned only with more than two outcomes.

► Example 1

We use the data from the “Television, School, and Family Smoking Prevention and Cessation Project” (Flay et al. 1988; Rabe-Hesketh and Skrondal 2012, chap. 11), where schools were randomly assigned into one of four groups defined by two treatment variables. Students within each school are nested in classes, and classes are nested in schools. In this example, we ignore the variability of classes within schools; see [example 2](#) of [ME] [meologit](#) for a model that incorporates the additional class-level variance component. The dependent variable is the tobacco and health knowledge score (`thk`) collapsed into four ordered categories. We regress the outcome on the treatment variables and their interaction and control for the pretreatment score.


```
. use http://www.stata-press.com/data/r13/tvsfpors
. xtset school
    panel variable:  school (unbalanced)
. xtlogit thk prethk cc##tv
Fitting comparison model:
Iteration 0:  log likelihood = -2212.775
Iteration 1:  log likelihood = -2125.509
Iteration 2:  log likelihood = -2125.1034
Iteration 3:  log likelihood = -2125.1032
Refining starting values:
Grid node 0:  log likelihood = -2136.2426
Fitting full model:
Iteration 0:  log likelihood = -2136.2426 (not concave)
Iteration 1:  log likelihood = -2120.2577
Iteration 2:  log likelihood = -2119.7574
Iteration 3:  log likelihood = -2119.7428
Iteration 4:  log likelihood = -2119.7428
Random-effects ordered logistic regression      Number of obs      =      1600
Group variable: school                        Number of groups    =       28
Random effects u_i ~ Gaussian                  Obs per group: min  =        18
                                                avg                =       57.1
                                                max                =       137
Integration method: mvaghermite                Integration points  =        12
                                                Wald chi2(4)       =       128.06
Log likelihood = -2119.7428                    Prob > chi2        =       0.0000
```

thk	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
prethk	.4032892	.03886	10.38	0.000	.327125	.4794534
1.cc	.9237904	.204074	4.53	0.000	.5238127	1.323768
1.tv	.2749937	.1977424	1.39	0.164	-.1125744	.6625618
cc#tv						
1 1	-.4659256	.2845963	-1.64	0.102	-1.023724	.0918728
/cut1	-.0884493	.1641062	-0.54	0.590	-.4100916	.233193
/cut2	1.153364	.165616	6.96	0.000	.8287625	1.477965
/cut3	2.33195	.1734199	13.45	0.000	1.992053	2.671846
/sigma2_u	.0735112	.0383106			.0264695	.2041551

LR test vs. ologit regression: chibar2(01) = 10.72 Prob>=chibar2 = 0.0005

The estimation table reports the parameter estimates, the estimated cutpoints ($\kappa_1, \kappa_2, \kappa_3$), and the estimated panel-level variance component labeled `sigma2_u`. The parameter estimates can be interpreted just as the output from a standard ordered logistic regression would be interpreted; see [R] **ologit**. For example, we find that students with higher preintervention scores tend to have higher postintervention scores.

Underneath the parameter estimates and the cutpoints, the table shows the estimated variance component. The estimate of σ_u^2 is 0.074 with standard error 0.038. The reported likelihood-ratio test shows that there is enough variability between schools to favor a random-effects ordered logistic regression over a standard ordered logistic regression.

□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [\[XT\] quadchk](#) for details and [\[XT\] xtprobit](#) for an [example](#).

Because the `xtologit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

□

Stored results

`xtologit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(k_cat)</code>	number of categories
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtologit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(covariates)</code>	list of covariates
<code>e(ivar)</code>	variable denoting groups
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(vce)</code>	<i>vce</i> type specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.

<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by margins
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(cat)</code>	category values
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtologit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} > k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = H(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i - \kappa_k)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, ν_i are independent and identically distributed $N(0, \sigma_\nu^2)$, and $\boldsymbol{\kappa}$ is a set of cutpoints $\kappa_1, \kappa_2, \dots, \kappa_{K-1}$, where K is the number of possible outcomes; and $H(\cdot)$ is the logistic cumulative distribution function.

From the above, we can derive the probability of observing outcome k for response y_{it} as

$$\begin{aligned} p_{itk} &\equiv \Pr(y_{it} = k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Pr(\kappa_{k-1} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} \leq \kappa_k) \\ &= \Pr(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i < \epsilon_{it} \leq \kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= H(\kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) - H(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= \frac{1}{1 + \exp(-\kappa_k + \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)} - \frac{1}{1 + \exp(-\kappa_{k-1} + \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)} \end{aligned}$$

where κ_0 is taken as $-\infty$ and κ_K is taken as $+\infty$. Here \mathbf{x}_{it} does not contain a constant term, because its effect is absorbed into the cutpoints.

We may also express this model in terms of a latent linear response, where observed ordinal responses y_{it} are generated from the latent continuous responses, such that

$$y_{it}^* = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it}$$

and

$$y_{it} = \begin{cases} 1 & \text{if } y_{it}^* \leq \kappa_1 \\ 2 & \text{if } \kappa_1 < y_{it}^* \leq \kappa_2 \\ \vdots & \\ K & \text{if } \kappa_{K-1} < y_{it}^* \end{cases}$$

The errors ϵ_{it} are distributed as logistic with mean zero and variance $\pi^2/3$ and are independent of ν_i .

Given a set of panel-level random effects ν_i , we can define the conditional distribution for response y_{it} as

$$\begin{aligned} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i) &= \prod_{k=1}^K p_{itk}^{I_k(y_{it})} \\ &= \exp \sum_{k=1}^K \left\{ I_k(y_{it}) \log(p_{itk}) \right\} \end{aligned}$$

where

$$I_k(y_{it}) = \begin{cases} 1 & \text{if } y_{it} = k \\ 0 & \text{otherwise} \end{cases}$$

For panel i , $i = 1, \dots, M$, the conditional distribution of $\mathbf{y}_i = (y_{i1}, \dots, y_{in_i})'$ is

$$\prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i)$$

and the panel-level likelihood l_i is given by

$$\begin{aligned} l_i(\boldsymbol{\beta}, \boldsymbol{\kappa}, \sigma_\nu^2) &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by mean–variance adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . The method of calculating the posterior mean and variance and using those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ is described in detail in [Naylor and Smith \(1982\)](#) and [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the j th iteration. That is, at the j th iteration of the optimization for l_i , we use

$$l_{i,j} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp \{ (a_m^*)^2 \} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1})$$

Letting

$$\tau_{i,m,j-1} = \sqrt{2}\hat{\sigma}_{i,j-1}a_m^* + \hat{\mu}_{i,j-1}$$

$$\hat{\mu}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1}) \frac{\sqrt{2}\hat{\sigma}_{i,j-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}, \boldsymbol{\kappa}, x_{it}, \tau_{i,m,j-1})}{l_{i,j}}$$

and

$$\hat{\sigma}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1})^2 \frac{\sqrt{2}\hat{\sigma}_{i,j-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}, \boldsymbol{\kappa}, x_{it}, \tau_{i,m,j-1})}{l_{i,j}} - (\hat{\mu}_{i,j})^2$$

This is repeated until $\hat{\mu}_{i,j}$ and $\hat{\sigma}_{i,j}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature with the option `intmethod(ghermite)`, where $\rho = \sigma_\nu^2/(\sigma_\nu^2 + 1)$:

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \boldsymbol{\kappa}, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} f \left\{ y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

xtlogit and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Allison, P. D. 2009. *Fixed Effects Regression Models*. Newbury Park, CA: Sage.
- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Conway, M. R. 1990. A random effects model for binary data. *Biometrics* 46: 317–328.
- Flay, B. R., B. R. Brannon, C. A. Johnson, W. B. Hansen, A. L. Ulene, D. A. Whitney-Saltiel, L. R. Gleason, S. Sussman, M. D. Gavin, K. M. Glowacz, D. F. Sobol, and D. C. Spiegel. 1988. The television, school, and family smoking cessation and prevention project: I. Theoretical basis and program development. *Preventive Medicine* 17: 585–607.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Neuhaus, J. M., J. D. Kalbfleisch, and W. W. Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59: 25–35.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Rabe-Hesketh, S., and A. Skrondal. 2012. *Multilevel and Longitudinal Modeling Using Stata*. 3rd ed. College Station, TX: Stata Press.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Twisk, J. W. R. 2013. *Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide*. 2nd ed. Cambridge: Cambridge University Press.
- Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtologit postestimation** — Postestimation tools for xtologit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtoprobit** — Random-effects ordered probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **meologit** — Multilevel mixed-effects ordered logistic regression
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **logit** — Logistic regression, reporting coefficients
- [U] **20 Estimation and postestimation commands**

[Description](#)
[Remarks and examples](#)

[Syntax for predict](#)
[Also see](#)

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtologit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] { stub*|newvar|newvarlist } [if] [in] [, statistic
      outcome(outcome) nooffset ]
```

<i>statistic</i>	Description
Main	
xb	linear prediction; the default
pu0	probability of the specified outcome (<code>outcome()</code>) assuming that the random effect is zero
stdp	standard error of the linear prediction

If you do not specify `outcome()`, `pu0` (with one new variable specified) assumes `outcome(#1)`.

You specify one or k new variables with `pu0`, where k is the number of outcomes.

You specify one new variable with `xb` and `stdp`.

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

`xb`, the default, calculates the linear prediction.

`pu0` calculates predicted probabilities, assuming that the random effect for that observation's panel is zero ($\nu = 0$).

You specify one or k new variables, where k is the number of categories of the dependent variable. If you specify the `outcome()` option, the probabilities will be predicted for the requested outcome only, in which case, you specify only one new variable. If you specify only one new variable and do not specify `outcome()`, `outcome(1)` is assumed.

`stdp` calculates the standard error of the linear prediction.

`outcome(outcome)` specifies the outcome for which the predicted probabilities are to be calculated. `outcome()` should contain either one value of the dependent variable or one of `#1`, `#2`, ..., with `#1` meaning the first category of the dependent variable, `#2` meaning the second category, etc.

`nooffset` is relevant only if you specified `offset(varname)` for `xtologit`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [\[XT\] xtologit](#), we modeled the tobacco and health knowledge score (`thk`)—coded 1, 2, 3, 4—among students as a function of two treatments (`cc` and `tv`) using a random-effects ordered logistic model. Here we refit the model, obtain the predicted probabilities for all 4 outcomes, and list the first 10 observations.

```
. use http://www.stata-press.com/data/r13/tvsfpor  
. xtset school  
    panel variable:  school (unbalanced)  
. xtologit thk prethk cc##tv  
    (output omitted)  
. predict pr*, pu0  
(1 missing values generated)  
. list thk pr1-pr4 in 1/10
```

	thk	pr1	pr2	pr3	pr4
1.	3	.1395758	.2200463	.2863958	.3539821
2.	4	.0675217	.1329124	.2484952	.5510707
3.	3	.0675217	.1329124	.2484952	.5510707
4.	4	.0977827	.1750507	.2765777	.4505889
5.	4	.0977827	.1750507	.2765777	.4505889
6.	3	.0675217	.1329124	.2484952	.5510707
7.	2	.1395758	.2200463	.2863958	.3539821
8.	4	.0675217	.1329124	.2484952	.5510707
9.	4	.0461466	.09731	.2089935	.6475499
10.	4	.0977827	.1750507	.2765777	.4505889

For each observation, our best guess for the predicted outcome is the one with the highest predicted probability. For example, for the very first observation in the table above, we would choose outcome 4 as the most likely to occur.

These predicted probabilities assume the random effects are zero for all panels. If you are interested in predicted probabilities that incorporate the random effects, see [\[ME\] meologit](#) and [\[ME\] meologit postestimation](#).



Also see

- [\[XT\] xtologit](#) — Random-effects ordered logistic models
- [\[U\] 20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtoprobit depvar [indepvars] [if] [in] [, options]
```

<i>options</i>	Description
Model	
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>startgrid</u> (<i>numlist</i>)	improve starting value of the random-intercept parameter by performing a grid search
<u>nodisplay</u>	suppress display of header and coefficients
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; see [XT] [xtset](#).
indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).
depvar and *indepvars* may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).
by, *fp*, and *statsby* are allowed; see [U] [11.1.10 Prefix commands](#).
`startgrid()`, `nodisplay`, and `coeflegend` do not appear in the dialog box.
See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Ordinal outcomes > Probit regression (RE)

Description

`xtoprobit` fits random-effects ordered probit models. The actual values taken on by the dependent variable are irrelevant, although larger values are assumed to correspond to “higher” outcomes. The conditional distribution of the dependent variable given the random effects is assumed to be multinomial, with success probability determined by the standard normal cumulative distribution function.

Options

Model

`offset(varname)`, `constraints(constraints)`, `collinear`; see [\[R\] estimation options](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtoprobit and the robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`; see [\[R\] estimation options](#).

`noskip`, `nocnsreport`; see [\[R\] estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwraon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [\[R\] estimation options](#).

Maximization

maximize_options: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [\[R\] maximize](#). These options are seldom used.

The following options are available with `xtoprobit` but are not shown in the dialog box:

`startgrid(numlist)` performs a grid search to improve the starting value of the random-intercept parameter. No grid search is performed by default unless the starting value is found to not be feasible; in this case, `xtoprobit` runs `startgrid(0.1 1 10)` and chooses the value that works best. You may already be using a default form of `startgrid()` without knowing it. If you see `xtoprobit` displaying Grid node 1, Grid node 2, ... following Grid node 0 in the iteration log, that is `xtoprobit` doing a default search because the original starting value was not feasible.

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtoprobit` fits random-effects ordered probit models. Ordered probit models are used to estimate relationships between an ordinal dependent variable and a set of independent variables. An *ordinal* variable is a variable that is categorical and ordered, for instance, “poor”, “good”, and “excellent”, which might indicate a person’s current health status or the repair record of a car. If there are only two outcomes, see [XT] [xtprobit](#), [XT] [xtlogit](#), and [XT] [xtcloglog](#). This entry is concerned only with more than two outcomes.

► Example 1

We use the data from the “Television, School, and Family Smoking Prevention and Cessation Project” (Flay et al. 1988; Rabe-Hesketh and Skrondal 2012, chap. 11), where schools were randomly assigned into one of four groups defined by two treatment variables. Students within each school are nested in classes, and classes are nested in schools. In this example, we ignore the variability of classes within schools; see [example 2](#) of [ME] [meoprobit](#) for a model that incorporates the additional class-level variance component. The dependent variable is the tobacco and health knowledge score (`thk`) collapsed into four ordered categories. We regress the outcome on the treatment variables and their interaction and control for the pretreatment score.


```
. use http://www.stata-press.com/data/r13/tvsfpors
. xtset school
      panel variable:  school (unbalanced)
. xtoprobit thk prethk cc##tv
Fitting comparison model:
Iteration 0:  log likelihood = -2212.775
Iteration 1:  log likelihood = -2127.8111
Iteration 2:  log likelihood = -2127.7612
Iteration 3:  log likelihood = -2127.7612
Refining starting values:
Grid node 0:  log likelihood = -2149.7302
Fitting full model:
Iteration 0:  log likelihood = -2149.7302 (not concave)
Iteration 1:  log likelihood = -2129.6838 (not concave)
Iteration 2:  log likelihood = -2123.5143
Iteration 3:  log likelihood = -2122.2896
Iteration 4:  log likelihood = -2121.7949
Iteration 5:  log likelihood = -2121.7716
Iteration 6:  log likelihood = -2121.7715
Random-effects ordered probit regression      Number of obs      =      1600
Group variable: school                       Number of groups    =       28
Random effects u_i ~ Gaussian                Obs per group: min  =        18
                                              avg               =       57.1
                                              max               =       137
Integration method: mvaghermite              Integration points   =       12
Wald chi2(4)                                =      128.05
Prob > chi2                                  =       0.0000
Log likelihood = -2121.7715
```

thk	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
prethk	.2369804	.0227739	10.41	0.000	.1923444	.2816164
1.cc	.5490957	.1255108	4.37	0.000	.303099	.7950923
1.tv	.1695405	.1215889	1.39	0.163	-.0687693	.4078504
cc##tv						
1 1	-.2951837	.1751969	-1.68	0.092	-.6385634	.0481959
/cut1	-.0682011	.1003374	-0.68	0.497	-.2648587	.1284565
/cut2	.67681	.1008836	6.71	0.000	.4790817	.8745382
/cut3	1.390649	.1037494	13.40	0.000	1.187304	1.593995
/sigma2_u	.0288527	.0146201			.0106874	.0778937

LR test vs. oprobit regression: chibar2(01) = 11.98 Prob>=chibar2 = 0.0003

The estimation table reports the parameter estimates, the estimated cutpoints ($\kappa_1, \kappa_2, \kappa_3$), and the estimated panel-level variance component labeled `sigma2_u`. The parameter estimates can be interpreted just as the output from a standard ordered probit regression would be interpreted; see [R] **oprobit**. For example, we find that students with higher preintervention scores tend to have higher postintervention scores.

Underneath the parameter estimates and the cutpoints, the table shows the estimated variance component. The estimate of σ_u^2 is 0.029 with standard error 0.015. The reported likelihood-ratio test shows that there is enough variability between schools to favor a random-effects ordered probit regression over a standard ordered probit regression.

□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [\[XT\] quadchk](#) for details and [\[XT\] xtoprobit](#) for an [example](#).

Because the `xtoprobit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

□

Stored results

`xtoprobit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(k_cat)</code>	number of categories
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtoprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(covariates)</code>	list of covariates
<code>e(ivar)</code>	variable denoting groups
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(vce)</code>	<i>vce</i> type specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.

<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by margins
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(cat)</code>	category values
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtoprobit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} > k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Phi(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i - \kappa_k)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, ν_i are independent and identically distributed $N(0, \sigma_\nu^2)$, and $\boldsymbol{\kappa}$ is a set of cutpoints $\kappa_1, \kappa_2, \dots, \kappa_{K-1}$, where K is the number of possible outcomes; and $\Phi(\cdot)$ is the standard normal cumulative distribution function.

From the above, we can derive the probability of observing outcome k for response y_{it} as

$$\begin{aligned} p_{itk} &\equiv \Pr(y_{it} = k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Pr(\kappa_{k-1} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} \leq \kappa_k) \\ &= \Pr(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i < \epsilon_{it} \leq \kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= \Phi(\kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) - \Phi(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \end{aligned}$$

where κ_0 is taken as $-\infty$, and κ_K is taken as $+\infty$. Here \mathbf{x}_{it} does not contain a constant term, because its effect is absorbed into the cutpoints.

We may also express this model in terms of a latent linear response, where observed ordinal responses y_{it} are generated from the latent continuous responses, such that

$$y_{it}^* = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it}$$

and

$$y_{it} = \begin{cases} 1 & \text{if } y_{it}^* \leq \kappa_1 \\ 2 & \text{if } \kappa_1 < y_{it}^* \leq \kappa_2 \\ \vdots & \\ K & \text{if } \kappa_{K-1} < y_{it}^* \end{cases}$$

The errors ϵ_{it} are distributed as standard normal with mean zero and variance one and are independent of ν_i .

Given a set of panel-level random effects ν_i , we can define the conditional distribution for response y_{it} as

$$\begin{aligned} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i) &= \prod_{k=1}^K p_{itk}^{I_k(y_{it})} \\ &= \exp \sum_{k=1}^K \left\{ I_k(y_{it}) \log(p_{itk}) \right\} \end{aligned}$$

where

$$I_k(y_{it}) = \begin{cases} 1 & \text{if } y_{it} = k \\ 0 & \text{otherwise} \end{cases}$$

For panel i , $i = 1, \dots, M$, the conditional distribution of $\mathbf{y}_i = (y_{i1}, \dots, y_{in_i})'$ is

$$\prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i)$$

and the panel-level likelihood l_i is given by

$$\begin{aligned} l_i(\boldsymbol{\beta}, \boldsymbol{\kappa}, \sigma_\nu^2) &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by mean–variance adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . The method of calculating the posterior mean and variance and using those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ is described in detail in [Naylor and Smith \(1982\)](#) and [Skron dal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the j th iteration. That is, at the j th iteration of the optimization for l_i , we use

$$l_{i,j} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp \{ (a_m^*)^2 \} g(y_{it}, \boldsymbol{\kappa}, x_{it}, \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1})$$

Letting

$$\tau_{i,m,j-1} = \sqrt{2}\hat{\sigma}_{i,j-1}a_m^* + \hat{\mu}_{i,j-1}$$

$$\hat{\mu}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1}) \frac{\sqrt{2}\hat{\sigma}_{i,j-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}, \boldsymbol{\kappa}, x_{it}, \tau_{i,m,j-1})}{l_{i,j}}$$

and

$$\hat{\sigma}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1})^2 \frac{\sqrt{2}\hat{\sigma}_{i,j-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}, \boldsymbol{\kappa}, x_{it}, \tau_{i,m,j-1})}{l_{i,j}} - (\hat{\mu}_{i,j})^2$$

This is repeated until $\hat{\mu}_{i,j}$ and $\hat{\sigma}_{i,j}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature with the option `intmethod(ghermite)`, where $\rho = \sigma_\nu^2/(\sigma_\nu^2 + 1)$:

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \boldsymbol{\kappa}, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} f \left\{ y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

xtoprobit and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Allison, P. D. 2009. *Fixed Effects Regression Models*. Newbury Park, CA: Sage.
- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Conway, M. R. 1990. A random effects model for binary data. *Biometrics* 46: 317–328.
- Flay, B. R., B. R. Brannon, C. A. Johnson, W. B. Hansen, A. L. Ulene, D. A. Whitney-Saltiel, L. R. Gleason, S. Sussman, M. D. Gavin, K. M. Glowacz, D. F. Sobol, and D. C. Spiegel. 1988. The television, school, and family smoking cessation and prevention project: I. Theoretical basis and program development. *Preventive Medicine* 17: 585–607.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Neuhaus, J. M., J. D. Kalbfleisch, and W. W. Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59: 25–35.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Rabe-Hesketh, S., and A. Skrondal. 2012. *Multilevel and Longitudinal Modeling Using Stata*. 3rd ed. College Station, TX: Stata Press.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Twisk, J. W. R. 2013. *Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide*. 2nd ed. Cambridge: Cambridge University Press.
- Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtoprobit postestimation** — Postestimation tools for xtoprobit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtologit** — Random-effects ordered logistic models
- [XT] **xtset** — Declare data to be panel data
- [ME] **meoprobit** — Multilevel mixed-effects ordered probit regression
- [R] **probit** — Probit regression
- [U] **20 Estimation and postestimation commands**

[Description](#)
[Remarks and examples](#)

[Syntax for predict](#)
[Also see](#)

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtoprobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] { stub*|newvar|newvarlist } [if] [in] [, statistic
outcome(outcome) nooffset ]
```

<i>statistic</i>	Description
Main	
xb	linear prediction; the default
pu0	probability of the specified outcome (outcome()) assuming that the random effect is zero
stdp	standard error of the linear prediction

If you do not specify outcome(), pu0 (with one new variable specified) assumes outcome(#1).
 You specify one or *k* new variables with pu0, where *k* is the number of outcomes.
 You specify one new variable with xb and stdp.
 These statistics are available both in and out of sample; type predict ... if e(sample) ... if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

pu0 calculates predicted probabilities, assuming that the random effect for that observation’s panel is zero ($\nu = 0$).

You specify one or *k* new variables, where *k* is the number of categories of the dependent variable. If you specify the outcome() option, the probabilities will be predicted for the requested outcome only, in which case, you specify only one new variable. If you specify only one new variable and do not specify outcome(), outcome(1) is assumed.

stdp calculates the standard error of the linear prediction.

outcome(outcome) specifies the outcome for which the predicted probabilities are to be calculated. outcome() should contain either one value of the dependent variable or one of #1, #2, ..., with #1 meaning the first category of the dependent variable, #2 meaning the second category, etc.

nooffset is relevant only if you specified offset(varname) for xtoprobit. This option modifies the calculations made by predict so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [\[XT\] xtoprobit](#), we modeled the tobacco and health knowledge score (`thk`)—coded 1, 2, 3, 4—among students as a function of two treatments (`cc` and `tv`) using a random-effects ordered probit model. Here we refit the model, obtain the predicted probabilities for all 4 outcomes, and list the first 10 observations.

```
. use http://www.stata-press.com/data/r13/tvsfpor  
. xtset school  
    panel variable:  school (unbalanced)  
. xtoprobit thk prethk cc##tv  
    (output omitted)  
. predict pr*, pu0  
(1 missing values generated)  
. list thk pr1-pr4 in 1/10
```

	thk	pr1	pr2	pr3	pr4
1.	3	.1375798	.2269989	.2788329	.3565884
2.	4	.0587658	.1472831	.2515963	.5423548
3.	3	.0587658	.1472831	.2515963	.5423548
4.	4	.0920497	.1878205	.2720888	.4480409
5.	4	.0920497	.1878205	.2720888	.4480409
6.	3	.0587658	.1472831	.2515963	.5423548
7.	2	.1375798	.2269989	.2788329	.3565884
8.	4	.0587658	.1472831	.2515963	.5423548
9.	4	.0357571	.1094559	.2204553	.6343318
10.	4	.0920497	.1878205	.2720888	.4480409

For each observation, our best guess for the predicted outcome is the one with the highest predicted probability. For example, for the very first observation in the table above, we would choose outcome 4 as the most likely to occur.

These predicted probabilities assume the random effects are zero for all panels. If you are interested in predicted probabilities that incorporate the random effects, see [\[ME\] meoprobit](#) and [\[ME\] meoprobit postestimation](#).



Also see

- [\[XT\] xtoprobit](#) — Random-effects ordered probit models
- [\[U\] 20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	Acknowledgments
References	Also see		

Syntax

```
xtpcse depvar [indepvars] [if] [in] [weight] [, options]
```

<i>options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>correlation(<u>i</u>ndependent)</code>	use independent autocorrelation structure
<code>correlation(<u>a</u>r1)</code>	use AR1 autocorrelation structure
<code>correlation(<u>p</u>sar1)</code>	use panel-specific AR1 autocorrelation structure
<code><u>r</u>hotype(<i>calc</i>)</code>	specify method to compute autocorrelation parameter; seldom used
<code>np1</code>	weight panel-specific autocorrelations by panel sizes
<code>hetonly</code>	assume panel-level heteroskedastic errors
<code><u>i</u>ndependent</code>	assume independent errors across panels
by/if/in	
<code><u>c</u>asewise</code>	include only observations with complete cases
<code><u>p</u>airwise</code>	include all available observations with nonmissing pairs
SE	
<code><u>n</u>mk</code>	normalize standard errors by $N - k$ instead of N
Reporting	
<code><u>l</u>evel(#)</code>	set confidence level; default is <code>level(95)</code>
<code><u>d</u>etail</code>	report list of gaps in time series
<code><i>display_options</i></code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code><u>c</u>oefflegend</code>	display legend instead of statistics

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.
indepvars may contain factor variables; see [U] 11.4.3 Factor variables.
depvar and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.
by and *statsby* are allowed; see [U] 11.1.10 Prefix commands.
weights and *aweight* are allowed; see [U] 11.1.6 weight.
`coefflegend` does not appear in the dialog box.
See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Contemporaneous correlation > Regression with panel-corrected standard errors (PCSE)

Description

xtpcse calculates panel-corrected standard error (PCSE) estimates for linear cross-sectional time-series models where the parameters are estimated by either OLS or Prais–Winsten regression. When computing the standard errors and the variance–covariance estimates, **xtpcse** assumes that the disturbances are, by default, heteroskedastic and contemporaneously correlated across panels.

See [XT] **xtgls** for the generalized least-squares estimator for these models.

Options

Model

noconstant; see [R] **estimation options**.

correlation(*corr*) specifies the form of assumed autocorrelation within panels.

correlation(*independent*), the default, specifies that there is no autocorrelation.

correlation(*ar1*) specifies that, within panels, there is first-order autocorrelation AR(1) and that the coefficient of the AR(1) process is common to all the panels.

correlation(*psar1*) specifies that, within panels, there is first-order autocorrelation and that the coefficient of the AR(1) process is specific to each panel. **psar1** stands for panel-specific AR(1).

rhotype(*calc*) specifies the method to be used to calculate the autocorrelation parameter. Allowed strings for *calc* are

regress	regression using lags; the default
freg	regression using leads
tscorr	time-series autocorrelation calculation
dw	Durbin–Watson calculation

All above methods are consistent and asymptotically equivalent; this is a rarely used option.

np1 specifies that the panel-specific autocorrelations be weighted by T_i rather than by the default $T_i - 1$ when estimating a common ρ for all panels, where T_i is the number of observations in panel i . This option has an effect only when panels are unbalanced and the **correlation**(*ar1*) option is specified.

hetonly and **independent** specify alternative forms for the assumed covariance of the disturbances across the panels. If neither is specified, the disturbances are assumed to be heteroskedastic (each panel has its own variance) and contemporaneously correlated across the panels (each pair of panels has its own covariance). This is the standard PCSE model.

hetonly specifies that the disturbances are assumed to be panel-level heteroskedastic only with no contemporaneous correlation across panels.

independent specifies that the disturbances are assumed to be independent across panels; that is, there is one disturbance variance common to all observations.

by/if/in

casewise and **pairwise** specify how missing observations in unbalanced panels are to be treated when estimating the interpanel covariance matrix of the disturbances. The default is **casewise** selection.

casewise specifies that the entire covariance matrix be computed only on the observations (periods) that are available for all panels. If an observation has missing data, all observations of that period are excluded when estimating the covariance matrix of disturbances. Specifying **casewise** ensures that the estimated covariance matrix will be of full rank and will be positive definite.

pairwise specifies that, for each element in the covariance matrix, all available observations (periods) that are common to the two panels contributing to the covariance be used to compute the covariance.

The **casewise** and **pairwise** options have an effect only when the panels are unbalanced and neither **hetonly** nor **independent** is specified.

SE

nmk specifies that standard errors be normalized by $N - k$, where k is the number of parameters estimated, rather than N , the number of observations. Different authors have used one or the other normalization. [Greene \(2012, 280\)](#) remarks that whether a degree-of-freedom correction improves the small-sample properties is an open question.

Reporting

level(#); see [\[R\] estimation options](#).

detail specifies that a detailed list of any gaps in the series be reported.

display_options: **noomitted**, **vsquish**, **noemptycells**, **baselevels**, **allbaselevels**, **nofvlabel**, **fvwrap(#)**, **fvwrapon(style)**, **cformat(%fmt)**, **pformat(%fmt)**, **sformat(%fmt)**, and **nolstretch**; see [\[R\] estimation options](#).

The following option is available with **xtpcse** but is not shown in the dialog box:

coeflegend; see [\[R\] estimation options](#).

Remarks and examples

xtpcse is an alternative to feasible generalized least squares (FGLS)—see [\[XT\] xtglm](#)—for fitting linear cross-sectional time-series models when the disturbances are not assumed to be independent and identically distributed (i.i.d.). Instead, the disturbances are assumed to be either heteroskedastic across panels or heteroskedastic and contemporaneously correlated across panels. The disturbances may also be assumed to be autocorrelated within panel, and the autocorrelation parameter may be constant across panels or different for each panel.

We can write such models as

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \epsilon_{it}$$

where $i = 1, \dots, m$ is the number of units (or panels); $t = 1, \dots, T_i$; T_i is the number of periods in panel i ; and ϵ_{it} is a disturbance that may be autocorrelated along t or contemporaneously correlated across i .

This model can also be written panel by panel as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_m \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_m \end{bmatrix} \boldsymbol{\beta} + \begin{bmatrix} \boldsymbol{\epsilon}_1 \\ \boldsymbol{\epsilon}_2 \\ \vdots \\ \boldsymbol{\epsilon}_m \end{bmatrix}$$

For a model with heteroskedastic disturbances and contemporaneous correlation but with no autocorrelation, the disturbance covariance matrix is assumed to be

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Omega} = \begin{bmatrix} \sigma_{11}\mathbf{I}_{11} & \sigma_{12}\mathbf{I}_{12} & \cdots & \sigma_{1m}\mathbf{I}_{1m} \\ \sigma_{21}\mathbf{I}_{21} & \sigma_{22}\mathbf{I}_{22} & \cdots & \sigma_{2m}\mathbf{I}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1}\mathbf{I}_{m1} & \sigma_{m2}\mathbf{I}_{m2} & \cdots & \sigma_{mm}\mathbf{I}_{mm} \end{bmatrix}$$

where σ_{ii} is the variance of the disturbances for panel i , σ_{ij} is the covariance of the disturbances between panel i and panel j when the panels' periods are matched, and \mathbf{I} is a T_i by T_i identity matrix with balanced panels. The panels need not be balanced for `xtpcse`, but the expression for the covariance of the disturbances will be more general if they are unbalanced.

This could also be written as

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Sigma}_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

where $\boldsymbol{\Sigma}$ is the panel-by-panel covariance matrix and \mathbf{I} is an identity matrix.

See [XT] `xtgls` for a full taxonomy and description of possible disturbance covariance structures.

`xtpcse` and `xtgls` follow two different estimation schemes for this family of models. `xtpcse` produces OLS estimates of the parameters when no autocorrelation is specified, or Prais–Winsten (see [TS] `prais`) estimates when autocorrelation is specified. If autocorrelation is specified, the estimates of the parameters are conditional on the estimates of the autocorrelation parameter(s). The estimate of the variance–covariance matrix of the parameters is asymptotically efficient under the assumed covariance structure of the disturbances and uses the FGLS estimate of the disturbance covariance matrix; see Kmenta (1997, 121).

`xtgls` produces full FGLS parameter and variance–covariance estimates. These estimates are conditional on the estimates of the disturbance covariance matrix and are conditional on any autocorrelation parameters that are estimated; see Kmenta (1997), Greene (2012), Davidson and MacKinnon (1993), or Judge et al. (1985).

Both estimators are consistent, as long as the conditional mean $(\mathbf{x}_{it}\boldsymbol{\beta})$ is correctly specified. If the assumed covariance structure is correct, FGLS estimates produced by `xtgls` are more efficient. Beck and Katz (1995) have shown, however, that the full FGLS variance–covariance estimates are typically unacceptably optimistic (anticonservative) when used with the type of data analyzed by most social scientists—10–20 panels with 10–40 periods per panel. They show that the OLS or Prais–Winsten estimates with PCSEs have coverage probabilities that are closer to nominal.

Because the covariance matrix elements, σ_{ij} , are estimated from panels i and j , using those observations that have common time periods, estimators for this model achieve their asymptotic behavior as the T_i s approach infinity. In contrast, the random- and fixed-effects estimators assume a different model and are asymptotic in the number of panels m ; see [XT] `xtreg` for details of the random- and fixed-effects estimators.

Although `xtpcse` allows other disturbance covariance structures, the term PCSE, as used in the literature, refers specifically to models that are both heteroskedastic and contemporaneously correlated across panels, with or without autocorrelation.

► Example 1: Controlling for heteroskedasticity and cross-panel correlation

Grunfeld and Griliches (1960) analyzed a company’s current-year gross investment (`invest`) as determined by the company’s prior year market value (`mvalue`) and the prior year’s value of the company’s plant and equipment (`kstock`). The dataset includes 10 companies over 20 years, from 1935 through 1954, and is a classic dataset for demonstrating cross-sectional time-series analysis. Greene (2012, 1112) reproduces the dataset.

To use `xtpcse`, the data must be organized in “long form”; that is, each observation must represent a record for a specific company at a specific time; see [D] [reshape](#). In the Grunfeld data, `company` is a categorical variable identifying the company, and `year` is a variable recording the year. Here are the first few records:

```
. use http://www.stata-press.com/data/r13/grunfeld
. list in 1/5
```

	company	year	invest	mvalue	kstock	time
1.	1	1935	317.6	3078.5	2.8	1
2.	1	1936	391.8	4661.7	52.6	2
3.	1	1937	410.6	5387.1	156.9	3
4.	1	1938	257.7	2792.2	209.2	4
5.	1	1939	330.8	4313.2	203.4	5

To compute PCSEs, Stata must be able to identify the panel to which each observation belongs and be able to match the periods across the panels. We tell Stata how to do this matching by specifying the panel and time variables with `xtset`; see [XT] [xtset](#). Because the data are annual, we specify the `yearly` option.

```
. xtset company year, yearly
      panel variable:  company (strongly balanced)
      time variable:  year, 1935 to 1954
                delta:  1 year
```

We can obtain OLS parameter estimates for a linear model of `invest` on `mvalue` and `kstock` while allowing the standard errors (and variance–covariance matrix of the estimates) to be consistent when the disturbances from each observation are not independent. Specifically, we want the standard errors to be robust to each company having a different variance of the disturbances and to each company’s observations being correlated with those of the other companies through time.

This model is fit in Stata by typing

```
. xtpcse invest mvalue kstock

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:      company      Number of obs      =      200
Time variable:      year      Number of groups    =      10
Panels:      correlated (balanced)  Obs per group: min =      20
Autocorrelation: no autocorrelation      avg      =      20
                                          max      =      20

Estimated covariances      =      55      R-squared      =      0.8124
Estimated autocorrelations =      0      Wald chi2(2)      =      637.41
Estimated coefficients      =      3      Prob > chi2      =      0.0000
```

invest	Panel-corrected		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
mvalue	.1155622	.0072124	16.02	0.000	.101426	.1296983
kstock	.2306785	.0278862	8.27	0.000	.1760225	.2853345
_cons	-42.71437	6.780965	-6.30	0.000	-56.00482	-29.42392



➤ Example 2: Comparing the FGLS and PCSE approaches

x_tgls will produce more efficient FGLS estimates of the models’ parameters, but with the disadvantage that the standard error estimates are conditional on the estimated disturbance covariance. [Beck and Katz \(1995\)](#) argue that the improvement in power using FGLS with such data is small and that the standard error estimates from FGLS are unacceptably optimistic (anticonservative).

The FGLS model is fit by typing

```
. xtglm invest mvalue kstock, panels(correlated)

Cross-sectional time-series FGLS regression

Coefficients: generalized least squares
Panels:      heteroskedastic with cross-sectional correlation
Correlation: no autocorrelation

Estimated covariances      =      55      Number of obs      =      200
Estimated autocorrelations =      0      Number of groups    =      10
Estimated coefficients      =      3      Time periods      =      20
                                          Wald chi2(2)      =      3738.07
                                          Prob > chi2      =      0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mvalue	.1127515	.0022364	50.42	0.000	.1083683	.1171347
kstock	.2231176	.0057363	38.90	0.000	.2118746	.2343605
_cons	-39.84382	1.717563	-23.20	0.000	-43.21018	-36.47746

The coefficients between the two models are close; the constants differ substantially, but we are generally not interested in the constant. As Beck and Katz observed, the standard errors for the FGLS model are 50%–100% smaller than those for the OLS model with PCSE.

If we were also concerned about autocorrelation of the disturbances, we could obtain a model with a common AR(1) parameter by specifying `correlation(ar1)`.


```
. xtpcse invest mvalue kstock, correlation(ar1)
(note: estimates of rho outside [-1,1] bounded to be in the range [-1,1])
Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)
Group variable:    company                Number of obs    =      200
Time variable:    year                    Number of groups  =      10
Panels:           correlated (balanced)    Obs per group: min =      20
Autocorrelation:  common AR(1)            avg              =      20
                                                    max              =      20
Estimated covariances =      55            R-squared         =    0.5468
Estimated autocorrelations =      1        Wald chi2(2)     =    93.71
Estimated coefficients =      3            Prob > chi2       =    0.0000
```

invest	Panel-corrected		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
mvalue	.0950157	.0129934	7.31	0.000	.0695492	.1204822
kstock	.306005	.0603718	5.07	0.000	.1876784	.4243317
_cons	-39.12569	30.50355	-1.28	0.200	-98.91154	20.66016
rho	.9059774					

The estimate of the autocorrelation parameter is high (0.906), and the standard errors are larger than for the model without autocorrelation, which is to be expected if there is autocorrelation.

► Example 3: Controlling for cross-panel correlation and autocorrelation

Let's estimate panel-specific autocorrelation parameters and change the method of estimating the autocorrelation parameter to the one typically used to estimate autocorrelation in time-series analysis.

```
. xtpcse invest mvalue kstock, correlation(pсар1) rhotype(tscorr)
Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)
Group variable:    company                Number of obs    =      200
Time variable:    year                    Number of groups  =      10
Panels:           correlated (balanced)    Obs per group: min =      20
Autocorrelation:  panel-specific AR(1)    avg              =      20
                                                    max              =      20
Estimated covariances =      55            R-squared         =    0.8670
Estimated autocorrelations =      10        Wald chi2(2)     =   444.53
Estimated coefficients =      3            Prob > chi2       =    0.0000
```

invest	Panel-corrected		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
mvalue	.1052613	.0086018	12.24	0.000	.0884021	.1221205
kstock	.3386743	.0367568	9.21	0.000	.2666322	.4107163
_cons	-58.18714	12.63687	-4.60	0.000	-82.95496	-33.41933
rhos =	.5135627	.87017	.9023497	.63368	.85715028752707

Beck and Katz (1995, 121) make a case against estimating panel-specific AR parameters, as opposed to one AR parameter for all panels.

➤ **Example 4: Controlling for heteroskedasticity only; not quite PCSEs**

We can also diverge from PCSEs to estimate standard errors that are panel corrected, but only for panel-level heteroskedasticity; that is, each company has a different variance of the disturbances. Allowing also for autocorrelation, we would type

```
. xtpcse invest mvalue kstock, correlation(ar1) hetonly
(note: estimates of rho outside [-1,1] bounded to be in the range [-1,1])
Prais-Winsten regression, heteroskedastic panels corrected standard errors
Group variable:      company      Number of obs      =      200
Time variable:      year      Number of groups      =      10
Panels:      heteroskedastic (balanced)      Obs per group: min =      20
Autocorrelation:      common AR(1)      avg      =      20
      max      =      20
Estimated covariances      =      10      R-squared      =      0.5468
Estimated autocorrelations =      1      Wald chi2(2)      =      91.72
Estimated coefficients      =      3      Prob > chi2      =      0.0000
```

invest	Het-corrected		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
mvalue	.0950157	.0130872	7.26	0.000	.0693653	.1206661
kstock	.306005	.061432	4.98	0.000	.1856006	.4264095
_cons	-39.12569	26.16935	-1.50	0.135	-90.41666	12.16529
rho	.9059774					

With this specification, we do not obtain what are referred to in the literature as PCSEs. These standard errors are in the same spirit as PCSEs but are from the asymptotic covariance estimates of OLS without allowing for contemporaneous correlation.

Stored results

xtpcse stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_gaps)</code>	number of gaps
<code>e(n_cf)</code>	number of estimated coefficients
<code>e(n_cv)</code>	number of estimated covariances
<code>e(n_cr)</code>	number of estimated correlations
<code>e(n_sigma)</code>	observations used to estimate elements of Sigma
<code>e(mss)</code>	model sum of squares
<code>e(df)</code>	degrees of freedom
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(r2)</code>	R -squared
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(rmse)</code>	root mean squared error
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	xtpcse
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(panels)</code>	contemporaneous covariance structure
<code>e(corr)</code>	correlation structure
<code>e(rhotype)</code>	type of estimated correlation
<code>e(rho)</code>	ρ
<code>e(cons)</code>	noconstant or ""
<code>e(missmeth)</code>	casewise or pairwise
<code>e(balance)</code>	balanced or unbalanced
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vctype)</code>	title used to label Std. Err.
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by margins
<code>e(asbalanced)</code>	factor variables fvset as asbalanced
<code>e(asobserved)</code>	factor variables fvset as asobserved

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\hat{\Sigma}$ matrix
<code>e(rhomat)</code>	vector of autocorrelation parameter estimates
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

If no autocorrelation is specified, the parameters β are estimated by OLS; see [R] [regress](#). If autocorrelation is specified, the parameters β are estimated by Prais–Winsten; see [TS] [prais](#).

When autocorrelation with panel-specific coefficients of correlation is specified (by using option `correlation(psar1)`), each panel-level ρ_i is computed from the residuals of an OLS regression across all panels; see [TS] [prais](#). When autocorrelation with a common coefficient of correlation is specified (by using option `correlation(ar1)`), the common correlation coefficient is computed as

$$\rho = \frac{\rho_1 + \rho_2 + \cdots + \rho_m}{m}$$

where ρ_i is the estimated autocorrelation coefficient for panel i and m is the number of panels.

The covariance of the OLS or Prais–Winsten coefficients is

$$\text{Var}(\beta) = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{\Omega}\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}$$

where $\mathbf{\Omega}$ is the full covariance matrix of the disturbances.

When the panels are balanced, we can write $\mathbf{\Omega}$ as

$$\mathbf{\Omega} = \mathbf{\Sigma}_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

where $\mathbf{\Sigma}$ is the m by m panel-by-panel covariance matrix of the disturbances; see [Remarks and examples](#).

`xtpcse` estimates the elements of $\mathbf{\Sigma}$ as

$$\hat{\Sigma}_{ij} = \frac{\epsilon_i' \epsilon_j}{T_{ij}}$$

where ϵ_i and ϵ_j are the residuals for panels i and j , respectively, that can be matched by period, and where T_{ij} is the number of residuals between the panels i and j that can be matched by time period.

When the panels are balanced (each panel has the same number of observations and all periods are common to all panels), $T_{ij} = T$, where T is the number of observations per panel.

When panels are unbalanced, `xtpcse` by default uses `casewise` selection, in which only those residuals from periods that are common to all panels are used to compute $\hat{\Sigma}_{ij}$. Here $T_{ij} = T^*$, where T^* is the number of periods common to all panels. When `pairwise` is specified, each $\hat{\Sigma}_{ij}$ is computed using all observations that can be matched by period between the panels i and j .

Acknowledgments

We thank the following people for helpful comments: Nathaniel Beck of the Department of Politics at New York University, Jonathan Katz of the Division of the Humanities and Social Science at California Institute of Technology, and Robert John Franzese Jr. of the Center for Political Studies at the Institute for Social Research at the University of Michigan.

References

- Beck, N. L., and J. N. Katz. 1995. What to do (and not to do) with time-series cross-section data. *American Political Science Review* 89: 634–647.
- Blackwell, J. L., III. 2005. Estimation and testing of fixed-effect panel-data systems. *Stata Journal* 5: 202–207.
- Davidson, R., and J. G. MacKinnon. 1993. *Estimation and Inference in Econometrics*. New York: Oxford University Press.
- Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Grunfeld, Y., and Z. Griliches. 1960. Is aggregation necessarily bad? *Review of Economics and Statistics* 42: 1–13.
- Hoechle, D. 2007. Robust standard errors for panel regressions with cross-sectional dependence. *Stata Journal* 7: 281–312.
- Judge, G. G., W. E. Griffiths, R. C. Hill, H. Lütkepohl, and T.-C. Lee. 1985. *The Theory and Practice of Econometrics*. 2nd ed. New York: Wiley.
- Kmenta, J. 1997. *Elements of Econometrics*. 2nd ed. Ann Arbor: University of Michigan Press.

Also see

- [XT] [xtpcse postestimation](#) — Postestimation tools for xtpcse
- [XT] [xtset](#) — Declare data to be panel data
- [XT] [xtgls](#) — Fit panel-data models by using GLS
- [XT] [xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] [xtregar](#) — Fixed- and random-effects linear models with an AR(1) disturbance
- [R] [regress](#) — Linear regression
- [TS] [newey](#) — Regression with Newey–West standard errors
- [TS] [prais](#) — Prais–Winsten and Cochrane–Orcutt regression
- [U] [20 Estimation and postestimation commands](#)

Description

The following postestimation commands are available after `xtpcse`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ¹	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

```
predict [type] newvar [if] [in] [, xb stdp]
```

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- `xb`, the default, calculates the linear prediction.
- `stdp` calculates the standard error of the linear prediction.

Also see

[XT] [xtpcse](#) — Linear regression with panel-corrected standard errors

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description
Options for RE model	Options for FE model	Options for PA model
Remarks and examples	Stored results	Methods and formulas
References	Also see	

Syntax

Random-effects (RE) model

```
xtpoisson depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

Conditional fixed-effects (FE) model

```
xtpoisson depvar [indepvars] [if] [in] [weight] , fe [FE_options]
```

Population-averaged (PA) model

```
xtpoisson depvar [indepvars] [if] [in] [weight] , pa [PA_options]
```


<i>RE_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>exposure</u> (<i>varname</i>)	include $\ln(\text{varname})$ in model with coefficient constrained to 1
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
<u>normal</u>	use a normal distribution for random effects instead of gamma
<u>constraints</u> (<i>constraints</i>)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>irr</u>	report incidence-rate ratios
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (<i>intmethod</i>)	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>FE_options</i>	Description
Model	
<code>fe</code>	use fixed-effects estimator
<code>exposure(<i>varname</i>)</code>	include $\ln(\textit{varname})$ in model with coefficient constrained to 1
<code>offset(<i>varname</i>)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>constraints(<i>constraints</i>)</code>	apply specified linear constraints
<code>collinear</code>	keep collinear variables
SE/Robust	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>oim</code> , <code>robust</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>irr</code>	report incidence-rate ratios
<code>nocnsreport</code>	do not display constraints
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<code>maximize_options</code>	control the maximization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>pa</code>	use population-averaged estimator
<code>exposure(varname)</code>	include $\ln(varname)$ in model with coefficient constrained to 1
<code>offset(varname)</code>	include <i>varname</i> in model with coefficient constrained to 1
Correlation	
<code>corr(correlation)</code>	within-panel correlation structure
<code>force</code>	estimate if observations unequally spaced in time
SE/Robust	
<code>vce(vctype)</code>	<i>vctype</i> may be <code>conventional</code> , <code>robust</code> , <code>bootstrap</code> , or <code>jackknife</code>
<code>nmp</code>	use divisor $N - P$ instead of the default N
<code>scale(parm)</code>	overrides the default scale parameter; <i>parm</i> may be <code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>irr</code>	report incidence-rate ratios
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<code>optimize_options</code>	control the optimization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

<i>correlation</i>	Description
<code>exchangeable</code>	exchangeable
<code>independent</code>	independent
<code>unstructured</code>	unstructured
<code>fixed matname</code>	user-specified
<code>ar #</code>	autoregressive of order <i>#</i>
<code>stationary #</code>	stationary of order <i>#</i>
<code>nonstationary #</code>	nonstationary of order <i>#</i>

A panel variable must be specified. For `xtpoisson`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).

devar and *indepvars* may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).

`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#). `fp` is allowed for the random-effects and fixed-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).

`weights`, `fweights`, and `pweights` are allowed for the population-averaged model and `weights` are allowed for the random-effects and fixed-effects models; see [U] [11.1.6 weight](#). Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Count outcomes > Poisson regression (FE, RE, PA)

Description

`xtpoisson` fits random-effects, conditional fixed-effects, and population-averaged Poisson models. Whenever we refer to a fixed-effects model, we mean the conditional fixed-effects model.

By default, the population-averaged model is an equal-correlation model; `xtpoisson`, `pa` assumes `corr(exchangeable)`. See [XT] [xtgee](#) for information on how to fit other population-averaged models.

Options for RE model

Model

`noconstant`; see [R] [estimation options](#).

`re`, the default, requests the random-effects estimator.

`exposure(varname)`, `offset(varname)`; see [R] [estimation options](#).

`normal` specifies that the random effects follow a normal distribution instead of a gamma distribution.

`constraints(constraints)`, `collinear`; see [R] [estimation options](#).

SE/Robust

`vce(vctype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtpoisson, re normal and the robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`; see [R] [estimation options](#).

`irr` reports exponentiated coefficients e^b rather than coefficients b . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`noskip`; see [R] [estimation options](#).

`nocnsreport`; see [R] [estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no!stretch`; see [R] [estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [estimation options](#). `normal` must also be specified.

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrntolerance`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtpoisson` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Options for FE model

Model

`fe` requests the fixed-effects estimator.

`exposure(varname)`, `offset(varname)`, `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(robust)` invokes a cluster-robust estimate of the VCE in which the ID variable specifies the clusters.

Reporting

`level(#)`; see [R] [estimation options](#).

`irr` reports exponentiated coefficients e^b rather than coefficients b . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`nocnsreport`; see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no1stretch`; see [R] [estimation options](#).

Maximization

maximize_options: `difficult`, `technique(algorithm-spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init-specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtpoisson` but is not shown in the dialog box:
`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator.

`exposure(varname)`, `offset(varname)`; see [R] [estimation options](#).

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp, scale(x2 | dev | phi | #)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

`irr` reports exponentiated coefficients e^b rather than coefficients b . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `no!stretch`; see [R] [estimation options](#).

Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtpoisson` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtpoisson` is a convenience command if you want the population-averaged model. Typing

```
. xtpoisson ..., ... pa exposure(time)
```

is equivalent to typing

```
. xtgee ..., ... family(poisson) link(log) corr(exchangeable) exposure(time)
```

Also see [XT] [xtgee](#) for information about `xtpoisson`.

By default or when `re` is specified, `xtpoisson` fits via maximum likelihood the random-effects model

$$\Pr(Y_{it} = y_{it} | \mathbf{x}_{it}) = F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, and $F(x, z) = \Pr(X = x)$, where X is Poisson distributed with mean $\exp(z)$. In the standard random-effects model, ν_i is assumed to be i.i.d. such that $\exp(\nu_i)$ is gamma with mean one and variance α , which is estimated from the data. If `normal` is specified, ν_i is assumed to be i.i.d. $N(0, \sigma_\nu^2)$.

► Example 1

We have data on the number of ship accidents for five different types of ships ([McCullagh and Nelder 1989](#), 205). We wish to analyze whether the “incident” rate is affected by the period in which the ship was constructed and operated. Our measure of exposure is months of service for the ship, and in this model, we assume that the exponentiated random effects are distributed as gamma with mean one and variance α .


```
. use http://www.stata-press.com/data/r13/ships
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr
Fitting Poisson model:
Iteration 0:   log likelihood = -147.37993
Iteration 1:   log likelihood = -80.372714
Iteration 2:   log likelihood = -80.116093
Iteration 3:   log likelihood = -80.115916
Iteration 4:   log likelihood = -80.115916
Fitting full model:
Iteration 0:   log likelihood = -79.653186
Iteration 1:   log likelihood = -76.990836   (not concave)
Iteration 2:   log likelihood = -74.824942
Iteration 3:   log likelihood = -74.811243
Iteration 4:   log likelihood = -74.811217
Iteration 5:   log likelihood = -74.811217

Random-effects Poisson regression              Number of obs      =      34
Group variable: ship                          Number of groups   =       5
Random effects u_i ~ Gamma                    Obs per group: min =       6
                                              avg =      6.8
                                              max =       7

Wald chi2(4) =      50.90
Prob > chi2   =      0.0000

Log likelihood = -74.811217
```

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.466305	.1734005	3.24	0.001	1.162957	1.848777
co_65_69	2.032543	.304083	4.74	0.000	1.515982	2.72512
co_70_74	2.356853	.3999259	5.05	0.000	1.690033	3.286774
co_75_79	1.641913	.3811398	2.14	0.033	1.04174	2.58786
_cons	.0013724	.0002992	-30.24	0.000	.0008952	.002104
ln(service)	1	(exposure)				
/lnalpha	-2.368406	.8474597			-4.029397	-.7074155
alpha	.0936298	.0793475			.0177851	.4929165

Likelihood-ratio test of alpha=0: chibar2(01) = 10.61 Prob>=chibar2 = 0.001

The output also includes a likelihood-ratio test of $\alpha = 0$, which compares the panel estimator with the pooled (Poisson) estimator.

We find that the incidence rate for accidents is significantly different for the periods of construction and operation of the ships and that the random-effects model is significantly different from the pooled model.

We may alternatively fit a fixed-effects specification instead of a random-effects specification:

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr fe
Iteration 0:   log likelihood = -80.738973
Iteration 1:   log likelihood = -54.857546
Iteration 2:   log likelihood = -54.641897
Iteration 3:   log likelihood = -54.641859
Iteration 4:   log likelihood = -54.641859

Conditional fixed-effects Poisson regression      Number of obs      =      34
Group variable: ship                             Number of groups   =       5
                                                Obs per group: min =       6
                                                avg               =      6.8
                                                max               =       7

                                                Wald chi2(4)       =      48.44
                                                Prob > chi2        =      0.0000

Log likelihood = -54.641859
```

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.468831	.1737218	3.25	0.001	1.164926	1.852019
co_65_69	2.008003	.3004803	4.66	0.000	1.497577	2.692398
co_70_74	2.26693	.384865	4.82	0.000	1.625274	3.161912
co_75_79	1.573695	.3669393	1.94	0.052	.9964273	2.485397
ln(service)	1	(exposure)				

Both of these models fit the same thing but will differ in efficiency, depending on whether the assumptions of the random-effects model are true.

We could have assumed that the random effects followed a normal distribution, $N(0, \sigma_v^2)$, instead of a “log-gamma” distribution, and obtained

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr
> normal nolog
Random-effects Poisson regression      Number of obs      =      34
Group variable: ship                  Number of groups   =       5
Random effects u_i ~ Gaussian         Obs per group: min =       6
                                                avg               =      6.8
                                                max               =       7

Integration method: mvaghermite       Integration points =      12
Wald chi2(4) = 50.95
Prob > chi2 = 0.0000

Log likelihood = -74.780982
```

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.466677	.1734403	3.24	0.001	1.163259	1.849236
co_65_69	2.032604	.3040933	4.74	0.000	1.516025	2.725205
co_70_74	2.357045	.3998397	5.05	0.000	1.690338	3.286717
co_75_79	1.646935	.3820235	2.15	0.031	1.045278	2.594905
_cons	.0013075	.0002775	-31.28	0.000	.0008625	.001982
ln(service)	1	(exposure)				
/lnsig2u	-2.351868	.8586262	-2.74	0.006	-4.034745	-.6689918
sigma_u	.3085306	.1324562			.1330045	.7156988

```
Likelihood-ratio test of sigma_u=0: chibar2(01) = 10.67 Pr>=chibar2 = 0.001
```

The output includes the additional panel-level variance component. This is parameterized as the log of the variance $\ln(\sigma_v^2)$ (labeled `lnsig2u` in the output). The standard deviation σ_v is also included in the output labeled `sigma_u`.

When `sigma_u` is zero, the panel-level variance component is unimportant and the panel estimator is no different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (`poisson`) with the panel estimator. Here σ_ν is significantly greater than zero, so a panel estimator is indicated.

➤ Example 2

This time we fit a robust equal-correlation population-averaged model:

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) pa
> vce(robust) eform

Iteration 1: tolerance = .04083192
Iteration 2: tolerance = .00270188
Iteration 3: tolerance = .00030663
Iteration 4: tolerance = .00003466
Iteration 5: tolerance = 3.891e-06
Iteration 6: tolerance = 4.359e-07

GEE population-averaged model
Group variable:                ship      Number of obs      =      34
Link:                      log      Number of groups   =       5
Family:                    Poisson   Obs per group: min =       6
Correlation:                exchangeable      avg =      6.8
                                           max =       7
                                           Wald chi2(4)      =    252.94
Scale parameter:                1      Prob > chi2       =     0.0000
                                           (Std. Err. adjusted for clustering on ship)
```

accident	IRR	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.483299	.1197901	4.88	0.000	1.266153	1.737685
co_65_69	2.038477	.1809524	8.02	0.000	1.712955	2.425859
co_70_74	2.643467	.4093947	6.28	0.000	1.951407	3.580962
co_75_79	1.876656	.33075	3.57	0.000	1.328511	2.650966
_cons	.0010255	.0000721	-97.90	0.000	.0008935	.001177
ln(service)	1	(exposure)				

We may compare this with a pooled estimator with clustered robust-variance estimates:

```
. poisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service)
> vce(cluster ship) irr

Iteration 0:   log pseudolikelihood = -147.37993
Iteration 1:   log pseudolikelihood = -80.372714
Iteration 2:   log pseudolikelihood = -80.116093
Iteration 3:   log pseudolikelihood = -80.115916
Iteration 4:   log pseudolikelihood = -80.115916

Poisson regression                               Number of obs   =           34
                                                Wald chi2(3)     =           .
                                                Prob > chi2      =           .
Log pseudolikelihood = -80.115916                Pseudo R2       =        0.3438

                                                (Std. Err. adjusted for 5 clusters in ship)
```

accident	IRR	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.47324	.1287036	4.44	0.000	1.2414	1.748377
co_65_69	2.125914	.2850531	5.62	0.000	1.634603	2.764897
co_70_74	2.860138	.6213563	4.84	0.000	1.868384	4.378325
co_75_79	2.021926	.4265285	3.34	0.001	1.337221	3.057227
_cons	.0009609	.0000277	-240.66	0.000	.000908	.0010168
ln(service)	1	(exposure)				



□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [\[XT\] quadchk](#) for details and [\[XT\] xtprobit](#) for an [example](#).

Because the `xtpoisson`, `re normal` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



Stored results

`xtpoisson`, `re` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(alpha)</code>	value of α
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtpoisson</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(method)</code>	requested estimation method
<code>e(distrib)</code>	Γ ; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
-----------	-------------------------

xtpoisson, re normal stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(N_cd)	number of completely determined observations
e(k)	number of parameters
e(k_aux)	number of auxiliary parameters
e(k_eq)	number of equations in e(b)
e(k_eq_model)	number of equations in overall model test
e(k_dv)	number of dependent variables
e(df_m)	model degrees of freedom
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(ll_c)	log likelihood, comparison model
e(chi2)	χ^2
e(chi2_c)	χ^2 for comparison test
e(N_clust)	number of clusters
e(sigma_u)	panel-level standard deviation
e(n_quad)	number of quadrature points
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(p)	significance
e(rank)	rank of e(V)
e(rank0)	rank of e(V) for constant-only model
e(ic)	number of iterations
e(rc)	return code
e(converged)	1 if converged, 0 otherwise

Macros

e(cmd)	xtpoisson
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	re
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(clustvar)	name of cluster variable
e(offset)	linear offset variable
e(offset1)	ln(<i>varname</i>), where <i>varname</i> is variable from exposure()
e(chi2type)	Wald or LR; type of model χ^2 test
e(chi2_ct)	Wald or LR; type of model χ^2 test corresponding to e(chi2_c)
e(vce)	<i>vcetype</i> specified in vce()
e(vcetype)	title used to label Std. Err.
e(intmethod)	integration method
e(distrib)	Gaussian; the distribution of the random effect
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators
e(V_modelbased)	model-based variance

Functions

e(sample)	marks estimation sample
-----------	-------------------------

xtpoisson, fe stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(k)	number of parameters
e(k_eq)	number of equations in e(b)
e(k_eq_model)	number of equations in overall model test
e(k_dv)	number of dependent variables
e(df_m)	model degrees of freedom
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(ll_c)	log likelihood, comparison model
e(chi2)	χ^2
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(p)	significance
e(rank)	rank of e(V)
e(ic)	number of iterations
e(rc)	return code
e(converged)	1 if converged, 0 otherwise

Macros

e(cmd)	xtpoisson
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	fe
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(offset)	linear offset variable
e(chi2type)	Wald; type of model χ^2 test
e(vce)	vcetype specified in vce()
e(vcetype)	title used to label Std. Err.
e(method)	requested estimation method
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
-----------	-------------------------

xtpoisson, pa stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(chi2)	χ^2
e(p)	significance
e(df_pear)	degrees of freedom for Pearson χ^2
e(chi2_dev)	χ^2 test of deviance
e(chi2_dis)	χ^2 test of deviance dispersion
e(deviance)	deviance
e(dispers)	deviance dispersion
e(phi)	scale parameter
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(rank)	rank of e(V)
e(tol)	target tolerance
e(dif)	achieved tolerance
e(rc)	return code

Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtpoisson</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	Poisson
<code>e(link)</code>	log; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code> ; scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	covariance estimation method
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtpoisson`, `pa` reports the population-averaged results obtained by using `xtgee`, `family(poisson)` `link(log)` to obtain estimates. See [XT] [xtgee](#) for details about the methods and formulas.

`xtpoisson`, `fe` with robust standard errors implements the formula presented in Wooldridge (1999). The formula is a cluster–robust estimate of the VCE in which the ID variable specifies the clusters.

Although Hausman, Hall, and Griliches (1984) wrote the seminal article on the random-effects and fixed-effects models, Cameron and Trivedi (2013) provide a good textbook treatment. Allison (2009, chap. 4) succinctly discusses these models and illustrates the differences between them using Stata.

For a random-effects specification, we know that

$$\Pr(y_{i1}, \dots, y_{in_i} | \alpha_i, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \left(\prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \exp \left\{ -\exp(\alpha_i) \sum_{t=1}^{n_i} \lambda_{it} \right\} \exp \left(\alpha_i \sum_{t=1}^{n_i} y_{it} \right)$$

where $\lambda_{it} = \exp(\mathbf{x}_{it}\beta)$. We may rewrite the above as [defining $\epsilon_i = \exp(\alpha_i)$]

$$\begin{aligned} \Pr(y_{i1}, \dots, y_{in_i} | \epsilon_i, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) &= \left\{ \prod_{t=1}^{n_i} \frac{(\lambda_{it} \epsilon_i)^{y_{it}}}{y_{it}!} \right\} \exp \left(- \sum_{t=1}^{n_i} \lambda_{it} \epsilon_i \right) \\ &= \left(\prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \exp \left(- \epsilon_i \sum_{t=1}^{n_i} \lambda_{it} \right) \epsilon_i^{\sum_{t=1}^{n_i} y_{it}} \end{aligned}$$

We now assume that ϵ_i follows a gamma distribution with mean one and variance $1/\theta$ so that unconditional on ϵ_i

$$\begin{aligned} \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{X}_i) &= \frac{\theta^\theta}{\Gamma(\theta)} \left(\prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \int_0^\infty \exp \left(- \epsilon_i \sum_{t=1}^{n_i} \lambda_{it} \right) \epsilon_i^{\sum_{t=1}^{n_i} y_{it}} \epsilon_i^{\theta-1} \exp(-\theta \epsilon_i) d\epsilon_i \\ &= \frac{\theta^\theta}{\Gamma(\theta)} \left(\prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \int_0^\infty \exp \left\{ - \epsilon_i \left(\theta + \sum_{t=1}^{n_i} \lambda_{it} \right) \right\} \epsilon_i^{\theta + \sum_{t=1}^{n_i} y_{it} - 1} d\epsilon_i \\ &= \left(\prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \frac{\Gamma \left(\theta + \sum_{t=1}^{n_i} y_{it} \right)}{\Gamma(\theta)} \left(\frac{\theta}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \right)^\theta \left(\frac{1}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \right)^{\sum_{t=1}^{n_i} y_{it}} \end{aligned}$$

for $\mathbf{X}_i = (\mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i})$.

The log likelihood (assuming gamma heterogeneity) is then derived using

$$u_i = \frac{\theta}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \quad \lambda_{it} = \exp(\mathbf{x}_{it}\beta)$$

$$\Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i) = \frac{\prod_{t=1}^{n_i} \lambda_{it}^{y_{it}} \Gamma(\theta + \sum_{t=1}^{n_i} y_{it})}{\prod_{t=1}^{n_i} y_{it}! \Gamma(\theta) (\sum_{t=1}^{n_i} \lambda_{it})^{\sum_{t=1}^{n_i} y_{it}}} u_i^\theta (1 - u_i)^{\sum_{t=1}^{n_i} y_{it}}$$

such that the log likelihood may be written as

$$\begin{aligned} L &= \sum_{i=1}^n w_i \left\{ \log \Gamma \left(\theta + \sum_{t=1}^{n_i} y_{it} \right) - \sum_{t=1}^{n_i} \log \Gamma(1 + y_{it}) - \log \Gamma(\theta) + \theta \log u_i \right. \\ &\quad \left. + \log(1 - u_i) \sum_{t=1}^{n_i} y_{it} + \sum_{t=1}^{n_i} y_{it} (\mathbf{x}_{it}\beta) - \left(\sum_{t=1}^{n_i} y_{it} \right) \log \left(\sum_{t=1}^{n_i} \lambda_{it} \right) \right\} \end{aligned}$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

Alternatively, if we assume a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{X}_i) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \exp\left\{-\exp(z) + yz - \log(y!)\right\}.$$

The panel-level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, with the definition of $g(y_{it}, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$\begin{aligned} L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\boldsymbol{\beta} + \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i) \right] \end{aligned}$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2} \hat{\sigma}_{i,k-1} w_m^* \exp\{a_m^*\} g(y_{it}, x_{it}, \sqrt{2} \hat{\sigma}_{i,k-1} a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2} \hat{\sigma}_{i,k-1} a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2} \hat{\sigma}_{i,k-1} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2} \hat{\sigma}_{i,k-1} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of 1e–6; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$:

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it} \boldsymbol{\beta} + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [\[XT\] quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

For a fixed-effects specification, we know that

$$\begin{aligned}\Pr(Y_{it} = y_{it} | \mathbf{x}_{it}) &= \exp\{-\exp(\alpha_i + \mathbf{x}_{it}\boldsymbol{\beta})\} \exp(\alpha_i + \mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}} / y_{it}! \\ &= \frac{1}{y_{it}!} \exp\{-\exp(\alpha_i) \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i y_{it}\} \exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}} \\ &\equiv F_{it}\end{aligned}$$

Because we know that the observations are independent, we may write the joint probability for the observations within a panel as

$$\begin{aligned}\Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i) \\ &= \prod_{t=1}^{n_i} \frac{1}{y_{it}!} \exp\{-\exp(\alpha_i) \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i y_{it}\} \exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}} \\ &= \left(\prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}}}{y_{it}!} \right) \exp\left\{-\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i \sum_t y_{it}\right\}\end{aligned}$$

and we also know that the sum of n_i Poisson independent random variables, each with parameter λ_{it} for $t = 1, \dots, n_i$, is distributed as Poisson with parameter $\sum_t \lambda_{it}$. Thus

$$\begin{aligned}\Pr\left(\sum_t Y_{it} = \sum_t y_{it} | \mathbf{X}_i\right) &= \\ &= \frac{1}{(\sum_t y_{it})!} \exp\left\{-\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i \sum_t y_{it}\right\} \left\{\sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta})\right\}^{\sum_t y_{it}}\end{aligned}$$

So, the conditional likelihood is conditioned on the sum of the outcomes in the set (panel). The appropriate function is given by

$$\begin{aligned}\Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i, \sum_t Y_{it} = \sum_t y_{it}) &= \\ &= \frac{\left[\left(\prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}}}{y_{it}!} \right) \exp\left\{-\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i \sum_t y_{it}\right\} \right]}{\left[\frac{1}{(\sum_t y_{it})!} \exp\left\{-\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta}) + \alpha_i \sum_t y_{it}\right\} \left\{\sum_t \exp(\mathbf{x}_{it}\boldsymbol{\beta})\right\}^{\sum_t y_{it}} \right]} \\ &= \left(\sum_t y_{it} \right)! \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}}}{y_{it}! \{\sum_k \exp(\mathbf{x}_{ik}\boldsymbol{\beta})\}^{y_{it}}}\end{aligned}$$

which is free of α_i .

The conditional log likelihood is given by

$$\begin{aligned}
 L &= \log \prod_{i=1}^n \left[\left(\sum_{t=1}^{n_i} y_{it} \right)! \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\boldsymbol{\beta})^{y_{it}}}{\sum_{\ell=1}^{n_i} \exp(\mathbf{x}_{i\ell}\boldsymbol{\beta})^{y_{it}}} \right]^{w_i} \\
 &= \log \prod_{i=1}^n \left\{ \frac{(\sum_t y_{it})!}{\prod_{t=1}^{n_i} y_{it}!} \prod_{t=1}^{n_i} p_{it}^{y_{it}} \right\}^{w_i} \\
 &= \sum_{i=1}^n w_i \left\{ \log \Gamma \left(\sum_{t=1}^{n_i} y_{it} + 1 \right) - \sum_{t=1}^{n_i} \log \Gamma(y_{it} + 1) + \sum_{t=1}^{n_i} y_{it} \log p_{it} \right\}
 \end{aligned}$$

where

$$p_{it} = e^{\mathbf{x}_{it}\boldsymbol{\beta}} / \sum_{\ell} e^{\mathbf{x}_{i\ell}\boldsymbol{\beta}}$$

xtpoisson, re normal and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where `panelvar` is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Allison, P. D. 2009. *Fixed Effects Regression Models*. Newbury Park, CA: Sage.
- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Cameron, A. C., and P. K. Trivedi. 2013. *Regression Analysis of Count Data*. 2nd ed. New York: Cambridge University Press.
- Cummings, P. 2011. Estimating adjusted risk ratios for matched and unmatched data: An update. *Stata Journal* 11: 290–298.
- Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Hardin, J. W., and J. M. Hilbe. 2012. *Generalized Linear Models and Extensions*. 3rd ed. College Station, TX: Stata Press.
- Hausman, J. A., B. H. Hall, and Z. Griliches. 1984. Econometric models for count data with an application to the patents–R & D relationship. *Econometrica* 52: 909–938.

- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- McCullagh, P., and J. A. Nelder. 1989. *Generalized Linear Models*. 2nd ed. London: Chapman & Hall/CRC.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Wooldridge, J. M. 1999. Distribution-free estimation of some nonlinear panel data models. *Journal of Econometrics* 90: 77–97.
- . 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtpoisson postestimation** — Postestimation tools for xtpoisson
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models
- [XT] **xtset** — Declare data to be panel data
- [ME] **mepoisson** — Multilevel mixed-effects Poisson regression
- [ME] **meqrpoisson** — Multilevel mixed-effects Poisson regression (QR decomposition)
- [MI] **estimation** — Estimation commands for use with mi estimate
- [R] **poisson** — Poisson regression
- [U] **20 Estimation and postestimation commands**

Description
Remarks and examples

Syntax for predict
Methods and formulas

Menu for predict
Also see

Options for predict

Description

The following postestimation commands are available after `xtpoisson`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtpoisson`, `pa`.
² `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

Random-effects (RE) and fixed-effects (FE) models

```
predict [type] newvar [if] [in] [, RE/FE_statistic nooffset]
```

Population-averaged (PA) model

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```


<i>RE/FE_statistic</i>	Description
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>nu0</code>	predicted number of events; assumes fixed or random effect is zero
<code>iru0</code>	predicted incidence rate; assumes fixed or random effect is zero
<code>pr0(<i>n</i>)</code>	probability $\Pr(y_j = n)$ assuming the random effect is zero; only allowed after <code>xtpoisson, re</code>
<code>pr0(<i>a</i>,<i>b</i>)</code>	probability $\Pr(a \leq y_j \leq b)$ assuming the random effect is zero; only allowed after <code>xtpoisson, re</code>

<i>PA_statistic</i>	Description
Main	
<code>mu</code>	predicted number of events; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted number of events
<code>xb</code>	linear prediction
<code>pr(<i>n</i>)</code>	probability $\Pr(y_j = n)$
<code>pr(<i>a</i>,<i>b</i>)</code>	probability $\Pr(a \leq y_j \leq b)$
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to \mathbf{x}_j/β

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

`xb` calculates the linear prediction. This is the default for the random-effects and fixed-effects models.

`mu` and `rate` both calculate the predicted number of events. `mu` takes into account the `offset()`, and `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.

`stdp` calculates the standard error of the linear prediction.

`nu0` calculates the predicted number of events, assuming a zero random or fixed effect.

`iru0` calculates the predicted incidence rate, assuming a zero random or fixed effect.

`pr0(n)` calculates the probability $\Pr(y_j = n)$ assuming the random effect is zero, where *n* is a nonnegative integer that may be specified as a number or a variable (only allowed after `xtpoisson, re`).

`pr0(a,b)` calculates the probability $\Pr(a \leq y_j \leq b)$ assuming the random effect is zero, where *a* and *b* are nonnegative integers that may be specified as numbers or variables (only allowed after `xtpoisson, re`);

b missing (*b* ≥ .) means $+\infty$;

`pr0(20,.)` calculates $\Pr(y_j \geq 20)$;

`pr0(20,b)` calculates $\Pr(y_j \geq 20)$ in observations for which *b* ≥ . and calculates $\Pr(20 \leq y_j \leq b)$ elsewhere.

`pr0(.,b)` produces a syntax error. A missing value in an observation of the variable *a* causes a missing value in that observation for `pr0(a,b)`.

`pr(n)` calculates the probability $\Pr(y_j = n)$, where *n* is a nonnegative integer that may be specified as a number or a variable (only allowed after `xtpoisson, pa`).

`pr(a,b)` calculates the probability $\Pr(a \leq y_j \leq b)$ (only allowed after `xtpoisson, pa`). The syntax for this option is analogous to that used with `pr0(a,b)`.

`score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\beta) / \partial (\mathbf{x}_j\beta)$.

`nooffset` is relevant only if you specified `offset(varname)` for `xtpoisson`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 1](#) of [\[XT\] xtpoisson](#), we fit a random-effects model of the number of accidents experienced by five different types of ships on the basis of when the ships were constructed and operated. Here we obtain the predicted number of accidents for each observation, assuming that the random effect for each panel is zero:

```
. use http://www.stata-press.com/data/r13/ships
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exposure(service) irr
  (output omitted)
. predict n_acc, nu0
(6 missing values generated)
. summarize n_acc
```

Variable	Obs	Mean	Std. Dev.	Min	Max
n_acc	34	13.52307	23.15885	.0617592	83.31905

From these results, you may be tempted to conclude that some types of ships are safe, with a predicted number of accidents close to zero, whereas others are dangerous, because 1 observation is predicted to have more than 83 accidents.

However, when we fit the model, we specified the `exposure(service)` option. The variable `service` records the total number of months of operation for each type of ship constructed in and operated during particular years. Because ships experienced different utilization rates and thus were exposed to different levels of accident risk, we included `service` as our exposure variable. When comparing different types of ships, we must therefore predict the number of accidents, assuming that all ships faced the same exposure to risk. To do that, we use the `iru0` option with `predict`:


```
. predict acc_rate, iru0
. summarize acc_rate
```

Variable	Obs	Mean	Std. Dev.	Min	Max
acc_rate	40	.002975	.0010497	.0013724	.0047429

These results show that if each ship were used for 1 month, the expected number of accidents is 0.002975. Depending on the type of ship and years of construction and operation, the *incidence rate* of accidents ranges from 0.00137 to 0.00474.



Methods and formulas

The probabilities calculated using the `pr0(n)` option are the probability $\Pr(y_{it} = n)$ for a RE model assuming the random effect is zero. Define $\mu_{it} = \exp(\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it})$. The probabilities in `pr0(n)` are calculated as the probability that $y_{it} = n$, where y_{it} has a Poisson distribution with mean μ_{it} . Specifically,

$$\Pr(y_{it} = n) = (n!)^{-1} \exp(-\mu_{it})(\mu_{it})^n$$

Probabilities calculated using the `pr(n)` option after fitting a PA model are also calculated as described above.

Also see

- [XT] **xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models
- [U] **20 Estimation and postestimation commands**

Syntax	Menu	Description	Options for RE model
Options for PA model	Remarks and examples	Stored results	Methods and formulas
References	Also see		

Syntax

Random-effects (RE) model

```
xtprobit depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

Population-averaged (PA) model

```
xtprobit depvar [indepvars] [if] [in] [weight] , pa [PA_options]
```

RE_options	Description
<hr/>	
Model	
<u>no</u> constant	suppress constant term
re	use random-effects estimator; the default
<u>offset</u> (varname)	include varname in model with coefficient constrained to 1
<u>constraints</u> (constraints)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
asis	retain perfect predictor variables
SE/Robust	
vce(vcetype)	vcetype may be oim, <u>robust</u> , <u>cluster</u> clustvar, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (intmethod)	integration method; intmethod may be <u>myaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is intpoints(12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>pa</code>	use population-averaged estimator
<code>offset(<i>varname</i>)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>asis</code>	retain perfect predictor variables
Correlation	
<code>corr(<i>correlation</i>)</code>	within-panel correlation structure
<code>force</code>	estimate even if observations unequally spaced in time
SE/Robust	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>robust</code> , <code>bootstrap</code> , or <code>jackknife</code>
<code>nmp</code>	use divisor $N - P$ instead of the default N
<code>scale(<i>parm</i>)</code>	overrides the default scale parameter; <i>parm</i> may be <code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<code>optimize_options</code>	control the optimization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

<i>correlation</i>	Description
<code>exchangeable</code>	exchangeable
<code>independent</code>	independent
<code>unstructured</code>	unstructured
<code>fixed <i>matname</i></code>	user-specified
<code>ar #</code>	autoregressive of order <code>#</code>
<code>stationary #</code>	stationary of order <code>#</code>
<code>nonstationary #</code>	nonstationary of order <code>#</code>

A panel variable must be specified. For `xtprobit`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

`indepvars` may contain factor variables; see [U] [11.4.3 Factor variables](#).

`devar` and `indepvars` may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).

`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#). `fp` is allowed for the random-effects model.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).

`iweights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `iweights` are allowed for the random-effects model; see [U] [11.1.6 weight](#). Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Binary outcomes > Probit regression (RE, PA)

Description

`xtprobit` fits random-effects and population-averaged probit models. There is no command for a conditional fixed-effects model, as there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood. Unconditional fixed-effects probit models may be fit with the `probit` command with indicator variables for the panels. However, unconditional fixed-effects estimates are biased.

By default, the population-averaged model is an equal-correlation model; `xtprobit`, `pa` assumes `corr(exchangeable)`. See [XT] [xtgee](#) for information about how to fit other population-averaged models.

See [R] [logistic](#) for a list of related estimation commands.

Options for RE model

Model

`noconstant`; see [R] [estimation options](#).

`re` requests the random-effects estimator. `re` is the default if neither `re` nor `pa` is specified.

`offset(varname)`, `constraints(constraints)`, `collinear`; see [R] [estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtprobit](#), [re](#) and the [robust VCE estimator](#) in *Methods and formulas*.

Reporting

`level(#)`, `noskip`; see [R] [estimation options](#).

`nocnsreport`; see [R] [estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fml)`, `pformat(%fml)`, `sformat(%fml)`, and `nolstretch`; see [R] [estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [estimation options](#).

Maximization

maximize_options: difficult, technique(*algorithm_spec*), iterate(#), [no]log, trace, gradient, showstep, hessian, showtolerance, tolerance(#), ltolerance(#), nrtolerance(#), nonrntolerance, and from(*init_specs*); see [R] [maximize](#). These options are seldom used.

The following option is available with **xtprobit** but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator.

`offset`(*varname*); see [R] [estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

Correlation

`corr`(*correlation*) specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce`(*vcetype*) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce`(`conventional`), the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale`(*x2* | *dev* | *phi* | #); see [XT] [vce_options](#).

Reporting

`level`(#); see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Optimization

optimize_options control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtprobit` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

`xtprobit` is a convenience command for obtaining the population-averaged model. Typing

```
. xtprobit ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(probit) corr(exchangeable)
```

See also [XT] [xtgee](#) for information about `xtprobit`.

By default or when `re` is specified, `xtprobit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = \Phi(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for $i = 1, \dots, n$ panels, where $t = 1, \dots, n_i$, ν_i are i.i.d., $N(0, \sigma_\nu^2)$, and Φ is the standard normal cumulative distribution function.

Underlying this model is the variance components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} > 0$$

where ϵ_{it} are i.i.d. Gaussian distributed with mean zero and variance $\sigma_\epsilon^2 = 1$, independently of ν_i .

► Example 1: Random-effects model

We are studying unionization of women in the United States and are using the `union` dataset; see [XT] [xt](#). We wish to fit a random-effects model of union membership:


```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtprobit union age grade i.not_smsa south##c.year

Fitting comparison model:
Iteration 0:   log likelihood = -13864.23
Iteration 1:   log likelihood = -13545.541
Iteration 2:   log likelihood = -13544.385
Iteration 3:   log likelihood = -13544.385

Fitting full model:
rho = 0.0      log likelihood = -13544.385
rho = 0.1      log likelihood = -12237.655
rho = 0.2      log likelihood = -11590.282
rho = 0.3      log likelihood = -11211.185
rho = 0.4      log likelihood = -10981.319
rho = 0.5      log likelihood = -10852.793
rho = 0.6      log likelihood = -10808.759
rho = 0.7      log likelihood = -10865.57

Iteration 0:   log likelihood = -10807.712
Iteration 1:   log likelihood = -10599.332
Iteration 2:   log likelihood = -10552.287
Iteration 3:   log likelihood = -10552.225
Iteration 4:   log likelihood = -10552.225

Random-effects probit regression               Number of obs      =      26200
Group variable: idcode                       Number of groups   =      4434
Random effects u_i ~ Gaussian                Obs per group: min =         1
                                              avg   =         5.9
                                              max   =         12

Integration method: mvaghermite              Integration points =         12

Wald chi2(6)                                =      220.91
Prob > chi2                                  =      0.0000

Log likelihood = -10552.225
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0082967	.0084599	0.98	0.327	-.0082843	.0248778
grade	.0482731	.0099469	4.85	0.000	.0287776	.0677686
1.not_smsa	-.139657	.0460548	-3.03	0.002	-.2299227	-.0493913
1.south	-1.584394	.358473	-4.42	0.000	-2.286989	-.8818002
year	-.0039854	.0088399	-0.45	0.652	-.0213113	.0133406
south#c.year						
1	.0134017	.0044622	3.00	0.003	.0046559	.0221475
_cons	-1.668202	.4751819	-3.51	0.000	-2.599542	-.7368628
/lnsig2u	.6103616	.0458783			.5204418	.7002814
sigma_u	1.35687	.0311255			1.297217	1.419267
rho	.6480233	.0104643			.6272511	.6682502

Likelihood-ratio test of rho=0: chibar2(01) = 5984.32 Prob >= chibar2 = 0.000

The output includes the additional panel-level variance component, which is parameterized as the log of the variance $\ln(\sigma_\nu^2)$ (labeled `lnsig2u` in the output). The standard deviation σ_ν is also included in the output (labeled `sigma_u`) together with ρ (labeled `rho`), where

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + 1}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When ρ is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (probit) with the panel estimator.



□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially.

<code>. quadchk, nooutput</code>				
Refitting model <code>intpoints() = 8</code>				
Refitting model <code>intpoints() = 16</code>				
Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-10552.225	-10554.496 -2.2712569 .00021524	-10552.399 -.17396615 .00001649	Difference Relative difference
union: age	.00829671	.00828745 -9.265e-06 -.0011167	.00831488 .00001817 .00218987	Difference Relative difference
union: grade	.0482731	.04860277 .00032967 .00682917	.04826287 -.00001023 -.00021188	Difference Relative difference
union: 1.not_smsa	-.13965702	-.14057441 -.00091739 .00656891	-.13953521 .00012181 -.00087218	Difference Relative difference
union: 1.south	-1.5843944	-1.5909857 -.00659135 .00416017	-1.5843375 .00005689 -.00003591	Difference Relative difference
union: year	-.00398535	-.00397811 7.237e-06 -.00181578	-.00400181 -.00001646 .00412982	Difference Relative difference
union: 1.south#c.~r	.01340169	.01344457 .00004288 .00319946	.01340388 2.193e-06 .0001636	Difference Relative difference
union: _cons	-1.6682022	-1.6757524 -.00755024 .00452597	-1.6665327 .00166948 -.00100077	Difference Relative difference
lnsig2u: _cons	.61036163	.61780789 .00744626 .01219976	.60974814 -.00061349 -.00100513	Difference Relative difference

The results obtained for 12 quadrature points were closer to the results for 16 points than to the results for eight points. Although the relative and absolute differences are a bit larger than we would like, they are not large. We can increase the number of quadrature points with the `intpoints()` option; if we choose `intpoints(20)` and do another `quadchk` we will get acceptable results, with relative differences around 0.01%.

This is not the case if we use nonadaptive quadrature. Then the results we obtain are

```
. xtprobit union age grade i.not_smsa south##c.year, intmethod(ghermite)
Fitting comparison model:
Iteration 0:   log likelihood = -13864.23
Iteration 1:   log likelihood = -13545.541
Iteration 2:   log likelihood = -13544.385
Iteration 3:   log likelihood = -13544.385
Fitting full model:
rho = 0.0      log likelihood = -13544.385
rho = 0.1      log likelihood = -12237.655
rho = 0.2      log likelihood = -11590.282
rho = 0.3      log likelihood = -11211.185
rho = 0.4      log likelihood = -10981.319
rho = 0.5      log likelihood = -10852.793
rho = 0.6      log likelihood = -10808.759
rho = 0.7      log likelihood = -10865.57
Iteration 0:   log likelihood = -10808.759
Iteration 1:   log likelihood = -10594.349
Iteration 2:   log likelihood = -10560.913
Iteration 3:   log likelihood = -10560.876
Iteration 4:   log likelihood = -10560.876
Random-effects probit regression               Number of obs      =      26200
Group variable: idcode                       Number of groups   =      4434
Random effects u_i ~ Gaussian                Obs per group: min =         1
                                              avg   =        5.9
                                              max   =         12
Integration method: ghermite                  Integration points =        12
Wald chi2(6) =      218.99
Prob > chi2 =      0.0000
Log likelihood = -10560.876
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0093488	.0083385	1.12	0.262	-.0069945	.025692
grade	.0488014	.0101168	4.82	0.000	.0289728	.06863
1.not_smsa	-.1364862	.0462831	-2.95	0.003	-.2271995	-.045773
1.south	-1.592711	.3576715	-4.45	0.000	-2.293734	-.8916877
year	-.0053723	.0087219	-0.62	0.538	-.0224668	.0117223
south#c.year						
1	.0136764	.0044532	3.07	0.002	.0049482	.0224046
_cons	-1.575539	.4639881	-3.40	0.001	-2.484939	-.6661388
/lnsig2u	.5615976	.0432021			.476923	.6462722
sigma_u	1.324187	.0286038			1.269295	1.381453
rho	.6368221	.0099918			.617021	.6561699

Likelihood-ratio test of rho=0: `chibar2(01) = 5967.02 Prob >= chibar2 = 0.000`

We now check the stability of the quadrature technique for this nonadaptive quadrature model. We expect it to be less stable.


```
. quadchk, nooutput
Refitting model intpoints() = 8
Refitting model intpoints() = 16
```

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-10560.876	-10574.239 -13.362535 .00126529	-10555.792 5.0839579 -.0004814	Difference Relative difference
union: age	.00934876	.01264615 .0032974 .35270966	.00731888 -.00202987 -.21712744	Difference Relative difference
union: grade	.04880139	.05710089 .00829951 .17006703	.04432417 -.00447722 -.09174372	Difference Relative difference
union: 1.not_smsa	-.13648624	-.13327724 .003209 -.0235115	-.14094541 -.00445917 .03267123	Difference Relative difference
union: 1.south	-1.592711	-1.5275627 .06514823 -.04090399	-1.6059143 -.01320331 .00828983	Difference Relative difference
union: year	-.00537226	-.00867673 -.00330447 .61509968	-.00307042 .00230184 -.4284678	Difference Relative difference
union: 1.south#c.~r	.01367641	.01278071 -.0008957 -.06549266	.01369009 .00001368 .00100054	Difference Relative difference
union: _cons	-1.5755388	-1.4888646 .08667418 -.0550124	-1.6505526 -.0750138 .04761152	Difference Relative difference
lnsig2u: _cons	.56159763	.49290978 -.06868786 -.12230795	.58068904 .0190914 .03399481	Difference Relative difference

Once again, the results obtained for 12 quadrature points were closer to the results for 16 points than to the results for eight points. However, here the convergence point seems to be sensitive to the number of quadrature points, so we should not trust these results. We should increase the number of quadrature points with the `intpoints()` option and then use `quadchk` again. We should not use the results of a random-effects specification when there is evidence that the numeric technique for calculating the model is not stable (as shown by `quadchk`).

Generally, the relative differences in the coefficients should not change by more than 1% if the quadrature technique is stable. See [\[XT\] quadchk](#) for details. Increasing the number of quadrature points can often improve the stability, and for models with high `rho` we may need many. We can also switch between adaptive and nonadaptive quadrature. As a rule, adaptive quadrature, which is the default integration method, is much more flexible and robust.

Because the `xtprobit`, `re` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

➤ Example 2: Equal-correlation model

As an alternative to the random-effects specification, we can fit an equal-correlation probit model:

```
. xtprobit union age grade i.not_smsa south#c.year, pa
Iteration 1: tolerance = .12544249
Iteration 2: tolerance = .0034686
Iteration 3: tolerance = .00017448
Iteration 4: tolerance = 8.382e-06
Iteration 5: tolerance = 3.997e-07

GEE population-averaged model
Group variable:          idcode      Number of obs      =      26200
Link:                  probit        Number of groups   =      4434
Family:                 binomial      Obs per group: min =           1
Correlation:            exchangeable  avg               =       5.9
                                      max               =       12
                                      Wald chi2(6)      =     242.57
                                      Prob > chi2       =      0.0000

Scale parameter:          1          Wald > chi2       =      0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0089699	.0053208	1.69	0.092	-.0014586	.0193985
grade	.0333174	.0062352	5.34	0.000	.0210966	.0455382
1.not_smsa	-.0715717	.027543	-2.60	0.009	-.1255551	-.0175884
1.south	-1.017368	.207931	-4.89	0.000	-1.424905	-.6098308
year	-.0062708	.0055314	-1.13	0.257	-.0171122	.0045706
south#c.year						
1	.0086294	.00258	3.34	0.001	.0035727	.013686
_cons	-.8670997	.294771	-2.94	0.003	-1.44484	-.2893592

➤ Example 3: Population-averaged model

In [example 3](#) of [\[R\] probit](#), we showed the above results and compared them with `probit`, `vce(cluster id)`. `xtprobit` with the `pa` option allows a `vce(robust)` option (the random-effects estimator does not allow the `vce(robust)` specification), so we can obtain the population-averaged probit estimator with the robust variance calculation by typing


```
. xtprobit union age grade i.not_smsa south#c.year, pa vce(robust) nolog
GEE population-averaged model      Number of obs      =      26200
Group variable:                    idcode      Number of groups   =      4434
Link:                              probit      Obs per group: min =         1
Family:                            binomial      avg           =       5.9
Correlation:                       exchangeable      max           =       12
                                     Wald chi2(6)      =     156.33
Scale parameter:                    1          Prob > chi2      =     0.0000
                                     (Std. Err. adjusted for clustering on idcode)
```

union	Semirobust		z	P> z	[95% Conf. Interval]	
	Coef.	Std. Err.				
age	.0089699	.0051169	1.75	0.080	-.001059	.0189988
grade	.0333174	.0076425	4.36	0.000	.0183383	.0482965
1.not_smsa	-.0715717	.0348659	-2.05	0.040	-.1399076	-.0032359
1.south	-1.017368	.3026981	-3.36	0.001	-1.610645	-.4240906
year	-.0062708	.0055745	-1.12	0.261	-.0171965	.0046549
south#c.year						
1	.0086294	.0037866	2.28	0.023	.0012078	.0160509
_cons	-.8670997	.3243959	-2.67	0.008	-1.502904	-.2312955

These standard errors are similar to those shown for probit, `vce(cluster id)` in [\[R\] probit](#).

◀

➤ Example 4: Random-effects model with stable quadrature

In a [previous example](#), we showed how `quadchk` indicated that the quadrature technique was numerically unstable. Here we present an example in which the quadrature is stable.

In this example, we have (synthetic) data on whether workers complain to managers at fast-food restaurants. The covariates are `age` (in years of the worker), `grade` (years of schooling completed by the worker), `south` (equal to 1 if the restaurant is located in the South), `tenure` (the number of years spent on the job by the worker), `gender` (of the worker), `race` (of the worker), `income` (in thousands of dollars by the restaurant), `genderm` (gender of the manager), `burger` (equal to 1 if the restaurant specializes in hamburgers), and `chicken` (equal to 1 if the restaurant specializes in chicken). The model is given by


```
. use http://www.stata-press.com/data/r13/chicken
. xtprobit complain age grade south tenure gender race income genderm burger
> chicken, nolog
Random-effects probit regression               Number of obs      =      2763
Group variable: restaurant                   Number of groups   =       500
Random effects u_i ~ Gaussian                Obs per group: min =        3
                                           avg =       5.5
                                           max =        8
Integration method: mvaghermite              Integration points =       12
                                           Wald chi2(10)      =      126.59
Log likelihood = -1318.2088                  Prob > chi2        =       0.0000
```

complain	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	-.0430409	.0130211	-3.31	0.001	-.0685617	-.01752
grade	.0330934	.0264572	1.25	0.211	-.0187618	.0849486
south	.1012	.0707196	1.43	0.152	-.037408	.2398079
tenure	-.0440079	.0987099	-0.45	0.656	-.2374758	.14946
gender	.3318499	.0601382	5.52	0.000	.2139812	.4497185
race	.3417901	.0382251	8.94	0.000	.2668703	.4167098
income	-.0022702	.0008885	-2.56	0.011	-.0040117	-.0005288
genderm	.0524577	.0706585	0.74	0.458	-.0860305	.1909459
burger	.0448931	.0956151	0.47	0.639	-.1425091	.2322953
chicken	.1904714	.0953067	2.00	0.046	.0036737	.3772691
_cons	-.2145311	.6240549	-0.34	0.731	-1.437656	1.008594
/lnsig2u	-1.704494	.2502057			-2.194888	-1.214099
sigma_u	.4264557	.0533508			.333723	.5449563
rho	.1538793	.0325769			.1002105	.2289765

Likelihood-ratio test of rho=0: chibar2(01) = 29.91 Prob >= chibar2 = 0.000

Again we would like to check the stability of the quadrature technique of the model before interpreting the results. Given the estimate of ρ and the small size of the panels (between 3 and 8), we should find that the quadrature technique is numerically stable.


```
. quadchk, nooutput
```

```
Refitting model intpoints() = 8
```

```
Refitting model intpoints() = 16
```

Quadrature check

	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-1318.2088	-1318.2088 -2.002e-06 1.519e-09	-1318.2088 -1.194e-09 9.061e-13	Difference Relative difference
complain: age	-.04304086	-.04304086 -3.896e-10 9.051e-09	-.04304086 -2.625e-12 6.100e-11	Difference Relative difference
complain: grade	.0330934	.0330934 2.208e-11 6.673e-10	.0330934 1.867e-12 5.643e-11	Difference Relative difference
complain: south	.10119998	.10119999 2.369e-09 2.341e-08	.10119998 3.957e-11 3.910e-10	Difference Relative difference
complain: tenure	-.04400789	-.0440079 -3.362e-09 7.640e-08	-.04400789 -2.250e-11 5.114e-10	Difference Relative difference
complain: gender	.33184986	.33184986 3.190e-09 9.612e-09	.33184986 2.546e-11 7.673e-11	Difference Relative difference
complain: race	.34179006	.34179007 3.801e-09 1.112e-08	.34179006 2.990e-11 8.749e-11	Difference Relative difference
complain: income	-.00227021	-.00227021 -4.468e-11 1.968e-08	-.00227021 -9.252e-13 4.075e-10	Difference Relative difference
complain: genderm	.05245769	.05245769 1.963e-09 3.742e-08	.05245769 4.481e-11 8.542e-10	Difference Relative difference
complain: burger	.04489311	.04489311 4.173e-10 9.296e-09	.04489311 6.628e-12 1.476e-10	Difference Relative difference
complain: chicken	.19047138	.19047139 3.096e-09 1.625e-08	.19047138 4.916e-11 2.581e-10	Difference Relative difference
complain: _cons	-.21453112	-.21453111 1.281e-08 -5.972e-08	-.21453112 2.682e-10 -1.250e-09	Difference Relative difference
lnsig2u: _cons	-1.7044935	-1.7044934 1.255e-07 -7.365e-08	-1.7044935 -4.135e-10 2.426e-10	Difference Relative difference

The relative and absolute differences are all small between the default 12 quadrature points and the result with 16 points. We do not have any coefficients that have a large difference between the default 12 quadrature points and eight quadrature points.

We conclude that the quadrature technique is stable. Because the differences here are so small, we would plan on using and interpreting these results rather than trying to rerun with more quadrature points.



Stored results

`xtprobit`, `re` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	ρ
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xtprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vctype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtprobit`, `pa` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(df_pear)</code>	degrees of freedom for Pearson χ^2
<code>e(chi2_dev)</code>	χ^2 test of deviance
<code>e(chi2_dis)</code>	χ^2 test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>binomial</code>
<code>e(link)</code>	<code>probit</code> ; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2</code> , <code>dev</code> , <code>phi</code> , or <code>#</code> ; scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

`xtprobit` reports the population-averaged results obtained by using `xtgee`, `family(binomial)` `link(probit)` to obtain estimates.

Assuming a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} \Phi(z) & \text{if } y \neq 0 \\ 1 - \Phi(z) & \text{otherwise} \end{cases}$$

where Φ is the cumulative normal distribution.

The panel-level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel-level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp \{ (a_m^*)^2 \} g(y_{it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, with the definition of $g(y_{it}, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right]$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of $1e-6$; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where $\rho = \sigma_\nu^2/(\sigma_\nu^2 + 1)$:

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left(\frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

xtprobit, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where `panelvar` is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

References

- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Conway, M. R. 1990. A random effects model for binary data. *Biometrics* 46: 317–328.
- Frechette, G. R. 2001a. [sg158: Random-effects ordered probit](#). *Stata Technical Bulletin* 59: 23–27. Reprinted in *Stata Technical Bulletin Reprints*, vol. 10, pp. 261–266. College Station, TX: Stata Press.
- . 2001b. [sg158.1: Update to random-effects ordered probit](#). *Stata Technical Bulletin* 61: 12. Reprinted in *Stata Technical Bulletin Reprints*, vol. 10, pp. 266–267. College Station, TX: Stata Press.
- Guilkey, D. K., and J. L. Murphy. 1993. Estimation and testing in the random effects probit model. *Journal of Econometrics* 59: 301–317.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Neuhaus, J. M., J. D. Kalbfleisch, and W. W. Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59: 25–35.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.
- Stewart, M. B. 2006. [Maximum simulated likelihood estimation of random-effects dynamic probit models with autocorrelated errors](#). *Stata Journal* 6: 256–272.

Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.

Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

[XT] **xtprobit postestimation** — Postestimation tools for xtprobit

[XT] **quadchk** — Check sensitivity of quadrature approximation

[XT] **xtcloglog** — Random-effects and population-averaged cloglog models

[XT] **xtgee** — Fit population-averaged panel-data models by using GEE

[XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models

[XT] **xtset** — Declare data to be panel data

[ME] **meprobit** — Multilevel mixed-effects probit regression

[MI] **estimation** — Estimation commands for use with mi estimate

[R] **probit** — Probit regression

[U] **20 Estimation and postestimation commands**

[Description](#)
[Remarks and examples](#)

[Syntax for predict](#)
[Also see](#)

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtprobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtprobit`, `pa`.
² `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

Random-effects model

```
predict [type] newvar [if] [in] [ , RE_statistic nooffset ]
```

Population-averaged model

```
predict [type] newvar [if] [in] [ , PA_statistic nooffset ]
```


<i>RE_statistic</i>	Description
Main	
xb	linear prediction; the default
pu0	probability of a positive outcome
stdp	standard error of the linear prediction

<i>PA_statistic</i>	Description
Main	
mu	probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
rate	probability of <i>depvar</i>
xb	linear prediction
stdp	standard error of the linear prediction
score	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

- xb** calculates the linear prediction. This is the default for the random-effects model.
- pu0** calculates the probability of a positive outcome, assuming that the random effect for that observation's panel is zero ($\nu = 0$). This probability may not be similar to the proportion of observed outcomes in the group.
- stdp** calculates the standard error of the linear prediction.
- mu** and **rate** both calculate the predicted probability of *depvar*. **mu** takes into account the `offset()`, and **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify `offset()`. **mu** is the default for the population-averaged model.
- score** calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\beta) / \partial (\mathbf{x}_j\beta)$.
- nooffset** is relevant only if you specified `offset(varname)` for `xtprobit`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Remarks and examples

► Example 1

In [example 2](#) of [\[XT\] xtprobit](#), we fit a population-averaged model of union status on the woman's age and level of schooling, whether she lived in an urban area, whether she lived in the south, and the year observed. Here we compute the average marginal effects from that fitted model on the probability of being in a union.

```
. use http://www.stata-press.com/data/r13/union
(NLS Women 14-24 in 1968)

. xtprobit union age grade i.not_smsa south##c.year, pa
(output omitted)

. margins, dydx(*)
Average marginal effects          Number of obs   =       26200
Model VCE      : Conventional
Expression    : Pr(union != 0), predict()
dy/dx w.r.t.  : age grade 1.not_smsa 1.south year
```

	Delta-method		z	P> z	[95% Conf. Interval]	
	dy/dx	Std. Err.				
age	.0025337	.0015035	1.69	0.092	-.0004132	.0054805
grade	.0094109	.0017566	5.36	0.000	.005968	.0128537
1.not_smsa	-.0199744	.0075879	-2.63	0.008	-.0348464	-.0051023
1.south	-.0910805	.0073315	-12.42	0.000	-.10545	-.076711
year	-.000938	.0015413	-0.61	0.543	-.0039589	.0020828

Note: dy/dx for factor levels is the discrete change from the base level.

On average, not living in a metropolitan area (`not_smsa = 0`) lowers the probability of being in a union by about two percentage points.

◀

Also see

[\[XT\] xtprobit](#) — Random-effects and population-averaged probit models

[\[U\] 20 Estimation and postestimation commands](#)

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xtrc depvar indepvars [if] [in] [, options]
```

options	Description
Main	
<code>noconstant</code>	suppress constant term
<code>offset(varname)</code>	include <i>varname</i> in model with coefficient constrained to 1
SE	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>betas</code>	display group-specific best linear predictors
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified; use `xtset`; see [XT] [xtset](#).
indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).
`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#).
`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).
`coeflegend` does not appear in the dialog box.
See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Random-coefficients regression by GLS

Description

`xtrc` fits the [Swamy \(1970\)](#) random-coefficients linear regression model.

Options

Main
<code>noconstant</code> , <code>offset(varname)</code> ; see [R] estimation options

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level(#)`; see [R] [estimation options](#).

`betas` requests that the group-specific best linear predictors also be displayed.

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

The following option is available with `xtrc` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

In random-coefficients models, we wish to treat the parameter vector as a realization (in each panel) of a stochastic process. `xtrc` fits the Swamy (1970) random-coefficients model, which is suitable for linear regression of panel data. See Greene (2012, chap. 11) and Poi (2003) for more information about this and other panel-data models.

► Example 1

Greene (2012, 1112) reprints data from a classic study of investment demand by Grunfeld and Griliches (1960). In [XT] [xtgls](#), we use this dataset to illustrate many of the possible models that may be fit with the `xtgls` command. Although the models included in the `xtgls` command offer considerable flexibility, they all assume that there is no parameter variation across firms (the cross-sectional units).

To take a first look at the assumption of parameter constancy, we should `reshape` our data so that we may fit a simultaneous-equation model with `sureg`; see [R] [sureg](#). Because there are only five panels here, this is not too difficult.

```
. use http://www.stata-press.com/data/r13/invest2
. reshape wide invest market stock, i(time) j(company)
(note: j = 1 2 3 4 5)

Data                long    ->    wide

Number of obs.      100    ->    20
Number of variables   5     ->    16
j variable (5 values) company -> (dropped)
xij variables:
      invest    ->    invest1 invest2 ... invest5
      market    ->    market1 market2 ... market5
      stock     ->    stock1 stock2 ... stock5
```



```
. sureg (invest1 market1 stock1) (invest2 market2 stock2)
> (invest3 market3 stock3) (invest4 market4 stock4) (invest5 market5 stock5)
Seemingly unrelated regression
```

Equation	Obs	Parms	RMSE	"R-sq"	chi2	P
invest1	20	2	84.94729	0.9207	261.32	0.0000
invest2	20	2	12.36322	0.9119	207.21	0.0000
invest3	20	2	26.46612	0.6876	46.88	0.0000
invest4	20	2	9.742303	0.7264	59.15	0.0000
invest5	20	2	95.85484	0.4220	14.97	0.0006

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
invest1						
market1	.120493	.0216291	5.57	0.000	.0781007	.1628853
stock1	.3827462	.032768	11.68	0.000	.318522	.4469703
_cons	-162.3641	89.45922	-1.81	0.070	-337.7009	12.97279
invest2						
market2	.0695456	.0168975	4.12	0.000	.0364271	.1026641
stock2	.3085445	.0258635	11.93	0.000	.2578529	.3592362
_cons	.5043112	11.51283	0.04	0.965	-22.06042	23.06904
invest3						
market3	.0372914	.0122631	3.04	0.002	.0132561	.0613268
stock3	.130783	.0220497	5.93	0.000	.0875663	.1739997
_cons	-22.43892	25.51859	-0.88	0.379	-72.45443	27.57659
invest4						
market4	.0570091	.0113623	5.02	0.000	.0347395	.0792788
stock4	.0415065	.0412016	1.01	0.314	-.0392472	.1222602
_cons	1.088878	6.258805	0.17	0.862	-11.17815	13.35591
invest5						
market5	.1014782	.0547837	1.85	0.064	-.0058958	.2088523
stock5	.3999914	.1277946	3.13	0.002	.1495186	.6504642
_cons	85.42324	111.8774	0.76	0.445	-133.8525	304.6989

Here we instead fit a random-coefficients model:

```
. use http://www.stata-press.com/data/r13/invest2
. xtrc invest market stock
Random-coefficients regression
Group variable: company
Number of obs      =      100
Number of groups   =        5
Obs per group: min =        20
                  avg =       20.0
                  max =        20
Wald chi2(2)       =       17.55
Prob > chi2        =       0.0002
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
market	.0807646	.0250829	3.22	0.001	.0316031	.1299261
stock	.2839885	.0677899	4.19	0.000	.1511229	.4168542
_cons	-23.58361	34.55547	-0.68	0.495	-91.31108	44.14386

Test of parameter constancy: chi2(12) = 603.99 Prob > chi2 = 0.0000

Just as the results of our simultaneous-equation model do not support the assumption of parameter constancy, the test included with the random-coefficients model also indicates that the assumption is not valid for these data. With large panel datasets, we would not want to take the time to look at a simultaneous-equations model (aside from the fact that our doing so was subjective).



Stored results

`xtrc` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(df_chi2c)</code>	degrees of freedom for comparison χ^2 test
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xtrc</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\widehat{\Sigma}$ matrix
<code>e(beta_ps)</code>	matrix of best linear predictors
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_ps)</code>	matrix of variances for the best linear predictors; row i contains vec of variance matrix for group i predictor

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

Methods and formulas

In a random-coefficients model, the parameter heterogeneity is treated as stochastic variation. Assume that we write

$$\mathbf{y}_i = \mathbf{X}_i \boldsymbol{\beta}_i + \boldsymbol{\epsilon}_i$$

where $i = 1, \dots, m$, and $\boldsymbol{\beta}_i$ is the coefficient vector ($k \times 1$) for the i th cross-sectional unit, such that

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \boldsymbol{\nu}_i \quad E(\boldsymbol{\nu}_i) = \mathbf{0} \quad E(\boldsymbol{\nu}_i \boldsymbol{\nu}_i') = \boldsymbol{\Sigma}$$

Our goal is to find $\widehat{\boldsymbol{\beta}}$ and $\widehat{\boldsymbol{\Sigma}}$.

The derivation of the estimator assumes that the cross-sectional specific coefficient vector β_i is the outcome of a random process with mean vector β and covariance matrix Σ ,

$$\mathbf{y}_i = \mathbf{X}_i\beta_i + \epsilon_i = \mathbf{X}_i(\beta + \nu_i) + \epsilon_i = \mathbf{X}_i\beta + (\mathbf{X}_i\nu_i + \epsilon_i) = \mathbf{X}_i\beta + \omega_i$$

where $E(\omega_i) = \mathbf{0}$ and

$$E(\omega_i\omega_i') = E\left\{(\mathbf{X}_i\nu_i + \epsilon_i)(\mathbf{X}_i\nu_i + \epsilon_i)'\right\} = E(\epsilon_i\epsilon_i') + \mathbf{X}_iE(\nu_i\nu_i')\mathbf{X}_i' = \sigma_i^2\mathbf{I} + \mathbf{X}_i\Sigma\mathbf{X}_i' = \Pi_i$$

Stacking the m equations, we have

$$\mathbf{y} = \mathbf{X}\beta + \omega$$

where $\Pi \equiv E(\omega\omega')$ is a block diagonal matrix with Π_i , $i = 1 \dots m$, along the main diagonal and zeros elsewhere. The GLS estimator of $\hat{\beta}$ is then

$$\hat{\beta} = \left(\sum_i \mathbf{X}_i' \Pi_i^{-1} \mathbf{X}_i \right)^{-1} \sum_i \mathbf{X}_i' \Pi_i^{-1} \mathbf{y}_i = \sum_{i=1}^m \mathbf{W}_i \mathbf{b}_i$$

where

$$\mathbf{W}_i = \left\{ \sum_{i=1}^m (\Sigma + \mathbf{V}_i)^{-1} \right\}^{-1} (\Sigma + \mathbf{V}_i)^{-1}$$

$\mathbf{b}_i = (\mathbf{X}_i' \mathbf{X}_i)^{-1} \mathbf{X}_i' \mathbf{y}_i$ and $\mathbf{V}_i = \sigma_i^2 (\mathbf{X}_i' \mathbf{X}_i)^{-1}$, showing that the resulting GLS estimator is a matrix-weighted average of the panel-specific OLS estimators. The variance of $\hat{\beta}$ is

$$\text{Var}(\hat{\beta}) = \sum_{i=1}^m (\Sigma + \mathbf{V}_i)^{-1}$$

To calculate the above estimator $\hat{\beta}$ for the unknown Σ and \mathbf{V}_i parameters, we use the two-step approach suggested by [Swamy \(1970\)](#):

\mathbf{b}_i = OLS panel-specific estimator

$$\hat{\sigma}_i^2 = \frac{\hat{\epsilon}_i' \hat{\epsilon}_i}{n_i - k}$$

$$\hat{\mathbf{V}}_i = \hat{\sigma}_i^2 (\mathbf{X}_i' \mathbf{X}_i)^{-1}$$

$$\bar{\mathbf{b}} = \frac{1}{m} \sum_{i=1}^m \mathbf{b}_i$$

$$\hat{\Sigma} = \frac{1}{m-1} \left(\sum_{i=1}^m \mathbf{b}_i \mathbf{b}_i' - m \bar{\mathbf{b}} \bar{\mathbf{b}}' \right) - \frac{1}{m} \sum_{i=1}^m \hat{\mathbf{V}}_i$$

The two-step procedure begins with the usual OLS estimates of β_i . With those estimates, we may proceed by obtaining estimates of $\hat{\mathbf{V}}_i$ and $\hat{\Sigma}$ (and thus $\hat{\mathbf{W}}_i$) and then obtain an estimate of β .

Swamy (1970) further points out that the matrix $\widehat{\Sigma}$ may not be positive definite and that because the second term is of order $1/(mT)$, it is negligible in large samples. A simple and asymptotically expedient solution is simply to drop this second term and instead use

$$\widehat{\Sigma} = \frac{1}{m-1} \left(\sum_{i=1}^m \mathbf{b}_i \mathbf{b}_i' - m \bar{\mathbf{b}} \bar{\mathbf{b}}' \right)$$

As discussed by Judge et al. (1985, 541), the feasible best linear predictor of β_i is given by

$$\begin{aligned} \widehat{\beta}_i &= \widehat{\beta} + \widehat{\Sigma} \mathbf{X}_i' \left(\mathbf{X}_i \widehat{\Sigma} \mathbf{X}_i' + \widehat{\sigma}_i^2 \mathbf{I} \right)^{-1} \left(\mathbf{y}_i - \mathbf{X}_i \widehat{\beta} \right) \\ &= \left(\widehat{\Sigma}^{-1} + \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \left(\widehat{\Sigma}^{-1} \widehat{\beta} + \widehat{\mathbf{V}}_i^{-1} \mathbf{b}_i \right) \end{aligned}$$

The conventional variance of $\widehat{\beta}_i$ is given by

$$\text{Var}(\widehat{\beta}_i) = \text{Var}(\widehat{\beta}) + (\mathbf{I} - \mathbf{A}_i) \left\{ \widehat{\mathbf{V}}_i - \text{Var}(\widehat{\beta}) \right\} (\mathbf{I} - \mathbf{A}_i)'$$

where

$$\mathbf{A}_i = \left(\widehat{\Sigma}^{-1} + \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \widehat{\Sigma}^{-1}$$

To test the model, we may look at the difference between the OLS estimate of β , ignoring the panel structure of the data and the matrix-weighted average of the panel-specific OLS estimators. The test statistic suggested by Swamy (1970) is given by

$$\chi_{k(m-1)}^2 = \sum_{i=1}^m (\mathbf{b}_i - \bar{\beta}^*)' \widehat{\mathbf{V}}_i^{-1} (\mathbf{b}_i - \bar{\beta}^*) \quad \text{where} \quad \bar{\beta}^* = \left(\sum_{i=1}^m \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \sum_{i=1}^m \widehat{\mathbf{V}}_i^{-1} \mathbf{b}_i$$

Johnston and DiNardo (1997) have shown that the test is algebraically equivalent to testing

$$H_0 : \beta_1 = \beta_2 = \cdots = \beta_m$$

in the generalized (groupwise heteroskedastic) xtglsl model, where \mathbf{V} is block diagonal with i th diagonal element Π_i .

References

- Eberhardt, M. 2012. [Estimating panel time-series models with heterogeneous slopes](#). *Stata Journal* 12: 61–71.
- Greene, W. H. 2012. [Econometric Analysis](#). 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Grunfeld, Y., and Z. Griliches. 1960. Is aggregation necessarily bad? *Review of Economics and Statistics* 42: 1–13.
- Johnston, J., and J. DiNardo. 1997. *Econometric Methods*. 4th ed. New York: McGraw–Hill.
- Judge, G. G., W. E. Griffiths, R. C. Hill, H. Lütkepohl, and T.-C. Lee. 1985. *The Theory and Practice of Econometrics*. 2nd ed. New York: Wiley.
- Nichols, A. 2007. [Causal inference with observational data](#). *Stata Journal* 7: 507–541.
- Poi, B. P. 2003. [From the help desk: Swamy’s random-coefficients model](#). *Stata Journal* 3: 302–308.
- Swamy, P. A. V. B. 1970. Efficient inference in a random coefficient regression model. *Econometrica* 38: 311–323.
- . 1971. *Statistical Inference in Random Coefficient Regression Models*. New York: Springer.

Also see

- [XT] [xtrc postestimation](#) — Postestimation tools for xtrc
- [XT] [xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] [xtset](#) — Declare data to be panel data
- [ME] [mixed](#) — Multilevel mixed-effects linear regression
- [MI] [estimation](#) — Estimation commands for use with mi estimate
- [U] [20 Estimation and postestimation commands](#)

[Description](#)
Also see

[Syntax for predict](#)

[Menu for predict](#)

[Options for predict](#)

Description

The following postestimation commands are available after `xtrc`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ¹	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combination of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `forecast` is not appropriate with `mi` estimation results.

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>group(group)</code>	linear prediction based on group <i>group</i>

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

`xb`, the default, calculates the linear prediction using the mean parameter vector.

`stdp` calculates the standard error of the linear prediction.

`group(group)` calculates the linear prediction using the best linear predictors for group *group*.

`nooffset` is relevant only if you specified `offset(varname)` for `xtrc`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\mathbf{b}$ rather than $\mathbf{x}_{it}\mathbf{b} + \text{offset}_{it}$.

Also see

[XT] [xtrc](#) — Random-coefficients model

[U] [20 Estimation and postestimation commands](#)

Syntax	Menu	Description
Options for RE model	Options for BE model	Options for FE model
Options for MLE model	Options for PA model	Remarks and examples
Stored results	Methods and formulas	Acknowledgments
References	Also see	

Syntax

GLS random-effects (RE) model

```
xtreg depvar [indepvars] [if] [in] [, re RE_options]
```

Between-effects (BE) model

```
xtreg depvar [indepvars] [if] [in] , be [BE_options]
```

Fixed-effects (FE) model

```
xtreg depvar [indepvars] [if] [in] [weight] , fe [FE_options]
```

ML random-effects (MLE) model

```
xtreg depvar [indepvars] [if] [in] [weight] , mle [MLE_options]
```

Population-averaged (PA) model

```
xtreg depvar [indepvars] [if] [in] [weight] , pa [PA_options]
```

RE_options	Description
<hr/>	
Model	
re	use random-effects estimator; the default
sa	use Swamy–Arora estimator of the variance components
SE/Robust	
vce(vcetype)	vcetype may be conventional, <u>r</u> obust, <u>c</u> luster clustvar, <u>b</u> ootstrap, or <u>j</u> ackknife
Reporting	
<u>l</u> evel(#)	set confidence level; default is level(95)
<u>t</u> heta	report θ
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<u>c</u> oef <u>l</u> egend	display legend instead of statistics
<hr/>	

<i>BE_options</i>	Description
Model	
be	use between-effects estimator
wls	use weighted least squares
SE	
vce(<i>vcetype</i>)	<i>vcetype</i> may be conventional, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
level(#)	set confidence level; default is level(95)
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
coeflegend	display legend instead of statistics
<i>FE_options</i>	Description
Model	
fe	use fixed-effects estimator
SE/Robust	
vce(<i>vcetype</i>)	<i>vcetype</i> may be conventional, <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
level(#)	set confidence level; default is level(95)
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
coeflegend	display legend instead of statistics
<i>MLE_options</i>	Description
Model	
noconstant	suppress constant term
mle	use ML random-effects estimator
SE	
vce(<i>vcetype</i>)	<i>vcetype</i> may be oim, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
level(#)	set confidence level; default is level(95)
<i>display_options</i>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<i>maximize_options</i>	control the maximization process; seldom used
coeflegend	display legend instead of statistics

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> (<i>varname</i>)	include <i>varname</i> in model with coefficient constrained to 1
Correlation	
<u>corr</u> (<i>correlation</i>)	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> (<i>vcetype</i>)	<i>vcetype</i> may be <u>conventional</u> , <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default N
<u>rgf</u>	multiply the robust variance estimate by $(N - 1)/(N - P)$
<u>scale</u> (<i>parm</i>)	overrides the default scale parameter; <i>parm</i> may be <i>x2</i> , <i>dev</i> , <i>phi</i> , or <i>#</i>
Reporting	
<u>level</u> (<i>#</i>)	set confidence level; default is <code>level(95)</code>
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> <i>#</i>	autoregressive of order <i>#</i>
<u>stationary</u> <i>#</i>	stationary of order <i>#</i>
<u>nonstationary</u> <i>#</i>	nonstationary of order <i>#</i>

A panel variable must be specified. For `xtreg`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] [xtset](#).

indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).

depvar and *indepvars* may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).

`by`, `mi estimate`, and `statsby` are allowed; see [U] [11.1.10 Prefix commands](#). `fp` is allowed for the between-effects, fixed-effects, and maximum-likelihood random-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] [mi estimate](#).

`aweight`s, `fweight`s, and `pweight`s are allowed for the fixed-effects model. `iweight`s, `fweight`s, and `pweight`s are allowed for the population-averaged model. `iweight`s are allowed for the maximum-likelihood random-effects (MLE) model. See [U] [11.1.6 weight](#). Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Linear models > Linear regression (FE, RE, PA, BE)

Description

xtreg fits regression models to panel data. In particular, **xtreg** with the **be** option fits random-effects models by using the between regression estimator; with the **fe** option, it fits fixed-effects models (by using the within regression estimator); and with the **re** option, it fits random-effects models by using the GLS estimator (producing a matrix-weighted average of the between and within results). See [XT] **xtdata** for a faster way to fit fixed- and random-effects models.

Options for RE model

Model

re, the default, requests the GLS random-effects estimator.

sa specifies that the small-sample Swamy–Arora estimator individual-level variance component be used instead of the default consistent estimator. See **xtreg**, **re** in *Methods and formulas* for details.

SE/Robust

vce(vctype) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (**conventional**), that are robust to some kinds of misspecification (**robust**), that allow for intragroup correlation (**cluster clustvar**), and that use bootstrap or jackknife methods (**bootstrap**, **jackknife**); see [XT] **vce_options**.

vce(conventional), the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying **vce(robust)** is equivalent to specifying **vce(cluster panelvar)**; see **xtreg**, **re** in *Methods and formulas*.

Reporting

level(#); see [R] **estimation options**.

theta specifies that the output include the estimated value of θ used in combining the between and fixed estimators. For balanced data, this is a constant, and for unbalanced data, a summary of the values is presented in the header of the output.

display_options: **noomitted**, **vsquish**, **noemptycells**, **baselevels**, **allbaselevels**, **nofvlabel**, **fvwrap(#)**, **fvwrapon(style)**, **cformat(%fmt)**, **pformat(%fmt)**, **sformat(%fmt)**, and **nolstretch**; see [R] **estimation options**.

The following option is available with **xtreg** but is not shown in the dialog box:

coeflegend; see [R] **estimation options**.

Options for BE model

Model

`be` requests the between regression estimator.

`wls` specifies that, for unbalanced data, weighted least squares be used rather than the default OLS. Both methods produce consistent estimates. The true variance of the between-effects residual is $\sigma_\nu^2 + T_i\sigma_\epsilon^2$ (see [xtreg, be](#) in *Methods and formulas* below). WLS produces a “stabilized” variance of $\sigma_\nu^2/T_i + \sigma_\epsilon^2$, which is also not constant. Thus the choice between OLS and WLS amounts to which is more stable.

Comment: `xtreg, be` is rarely used anyway, but between estimates are an ingredient in the random-effects estimate. Our implementation of `xtreg, re` uses the OLS estimates for this ingredient, based on our judgment that σ_ν^2 is large relative to σ_ϵ^2 in most models. Formally, only a consistent estimate of the between estimates is required.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level(#)`; see [\[R\] estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fnt)`, `pformat(%fnt)`, `sformat(%fnt)`, and `no!stretch`; see [\[R\] estimation options](#).

The following option is available with `xtreg` but is not shown in the dialog box:

`coeflegend`; see [\[R\] estimation options](#).

Options for FE model

Model

`fe` requests the fixed-effects (within) regression estimator.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtreg, fe](#) in *Methods and formulas*.

Reporting

`level(#)`; see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

The following option is available with `xtreg` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for MLE model

Model

`noconstant`; see [R] [estimation options](#).

`mle` requests the maximum-likelihood random-effects estimator.

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation options](#).

display_options: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

Maximization

maximize_options: `iterate(#)`, `[no]log`, `trace`, `tolerance(#)`, `ltolerance(#)`, and `from(init_specs)`; see [R] [maximize](#). These options are seldom used.

The following option is available with `xtreg` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Options for PA model

Model

`noconstant`; see [R] [estimation options](#).

`pa` requests the population-averaged estimator. For linear regression, this is the same as a random-effects estimator (both interpretations hold).

`xtreg, pa` is equivalent to `xtgee, family(gaussian) link(id) corr(exchangeable)`, which are the defaults for the `xtgee` command. `xtreg, pa` allows all the relevant `xtgee` options such as `vce(robust)`. Whether you use `xtreg, pa` or `xtgee` makes no difference. See [XT] [xtgee](#).

`offset(varname)`; see [R] [estimation options](#).

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`; see [XT] [vce_options](#).

`rgf` specifies that the robust variance estimate is multiplied by $(N - 1)/(N - P)$, where N is the total number of observations and P is the number of coefficients estimated. This option can be used with `family(gaussian)` only when `vce(robust)` is either specified or implied by the use of `pweights`. Using this option implies that the robust variance estimate is not invariant to the scale of any weights used.

`scale(x2|dev|phi|#)`; see [XT] [vce_options](#).

Reporting

`level(#)`; see [R] [estimation_options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation_options](#).

Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`nolog` suppresses display of the iteration log.

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtreg` but is not shown in the dialog box: `coeflegend`; see [R] [estimation options](#).

Remarks and examples

If you have not read [XT] `xt`, please do so.

See Baltagi (2013, chap. 2) and Wooldridge (2013, chap. 14) for good overviews of fixed-effects and random-effects models. Allison (2009) provides perspective on the use of fixed- versus random-effects estimators and provides many examples using Stata.

Consider fitting models of the form

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} \quad (1)$$

In this model, $\nu_i + \epsilon_{it}$ is the error term that we have little interest in; we want estimates of β . ν_i is the unit-specific error term; it differs between units, but for any particular unit, its value is constant. In the pulmonary data of [XT] `xt`, a person who exercises less would presumably have a lower forced expiratory volume (FEV) year after year and so would have a negative ν_i .

ϵ_{it} is the “usual” error term with the usual properties (mean 0, uncorrelated with itself, uncorrelated with \mathbf{x} , uncorrelated with ν , and homoskedastic), although in a more thorough development, we could decompose $\epsilon_{it} = v_t + \omega_{it}$, assume that ω_{it} is a conventional error term, and better describe v_t .

Before making the assumptions necessary for estimation, let’s perform some useful algebra on (1). Whatever the properties of ν_i and ϵ_{it} , if (1) is true, it must also be true that

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i\beta + \nu_i + \bar{\epsilon}_i \quad (2)$$

where $\bar{y}_i = \sum_t y_{it}/T_i$, $\bar{\mathbf{x}}_i = \sum_t \mathbf{x}_{it}/T_i$, and $\bar{\epsilon}_i = \sum_t \epsilon_{it}/T_i$. Subtracting (2) from (1), it must be equally true that

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\beta + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3)$$

These three equations provide the basis for estimating β . In particular, `xtreg, fe` provides what is known as the fixed-effects estimator—also known as the within estimator—and amounts to using OLS to perform the estimation of (3). `xtreg, be` provides what is known as the between estimator and amounts to using OLS to perform the estimation of (2). `xtreg, re` provides the random-effects estimator and is a (matrix) weighted average of the estimates produced by the between and within estimators. In particular, the random-effects estimator turns out to be equivalent to estimation of

$$(y_{it} - \theta\bar{y}_i) = (1 - \theta)\alpha + (\mathbf{x}_{it} - \theta\bar{\mathbf{x}}_i)\beta + \{(1 - \theta)\nu_i + (\epsilon_{it} - \theta\bar{\epsilon}_i)\} \quad (4)$$

where θ is a function of σ_ν^2 and σ_ϵ^2 . If $\sigma_\nu^2 = 0$, meaning that ν_i is always 0, $\theta = 0$ and (1) can be estimated by OLS directly. Alternatively, if $\sigma_\epsilon^2 = 0$, meaning that ϵ_{it} is 0, $\theta = 1$ and the within estimator returns all the information available (which will, in fact, be a regression with an R^2 of 1).

For more reasonable cases, few assumptions are required to justify the fixed-effects estimator of (3). The estimates are, however, conditional on the sample in that the ν_i are not assumed to have a distribution but are instead treated as fixed and estimable. This statistical fine point can lead to difficulty when making out-of-sample predictions, but that aside, the fixed-effects estimator has much to recommend it.

More is required to justify the between estimator of (2), but the conditioning on the sample is not assumed because $\nu_i + \bar{\epsilon}_i$ is treated as an error term. Newly required is that we assume that ν_i and \bar{x}_i are uncorrelated. This follows from the assumptions of the OLS estimator but is also transparent: were ν_i and \bar{x}_i correlated, the estimator could not determine how much of the change in \bar{y}_i , associated with an increase in \bar{x}_i , to assign to β versus how much to attribute to the unknown correlation. (This, of course, suggests the use of an instrumental-variable estimator, \bar{z}_i , which is correlated with \bar{x}_i but uncorrelated with ν_i , though that approach is not implemented here.)

The random-effects estimator of (4) requires the same no-correlation assumption. In comparison with the between estimator, the random-effects estimator produces more efficient results, albeit ones with unknown small-sample properties. The between estimator is less efficient because it discards the over-time information in the data in favor of simple means; the random-effects estimator uses both the within and the between information.

All this would seem to leave the between estimator of (2) with no role (except for a minor, technical part it plays in helping to estimate σ_ν^2 and σ_ϵ^2 , which are used in the calculation of θ , on which the random-effects estimates depend). Let's, however, consider a variation on (1):

$$y_{it} = \alpha + \bar{x}_i\beta_1 + (\mathbf{x}_{it} - \bar{x}_i)\beta_2 + \nu_i + \epsilon_{it} \quad (1')$$

In this model, we postulate that changes in the average value of \mathbf{x} for an individual have a different effect from temporary departures from the average. In an economic situation, y might be purchases of some item and \mathbf{x} income; a change in average income should have more effect than a transitory change. In a clinical situation, y might be a physical response and \mathbf{x} the level of a chemical in the brain; the model allows a different response to permanent rather than transitory changes.

The variations of (2) and (3) corresponding to (1') are

$$\bar{y}_i = \alpha + \bar{x}_i\beta_1 + \nu_i + \bar{\epsilon}_i \quad (2')$$

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{x}_i)\beta_2 + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3')$$

That is, the between estimator estimates β_1 and the within β_2 , and neither estimates the other. Thus even when estimating equations like (1), it is worth comparing the within and between estimators. Differences in results can suggest models like (1'), or at the least some other specification error.

Finally, it is worth understanding the role of the between and within estimators with regressors that are constant over time or constant over units. Consider the model

$$y_{it} = \alpha + \mathbf{x}_{it}\beta_1 + \mathbf{s}_i\beta_2 + \mathbf{z}_t\beta_3 + \nu_i + \epsilon_{it} \quad (1'')$$

This model is the same as (1), except that we explicitly identify the variables that vary over both time and i (\mathbf{x}_{it} , such as output or FEV); variables that are constant over time (\mathbf{s}_i , such as race or sex); and variables that vary solely over time (\mathbf{z}_t , such as the consumer price index or age in a cohort study). The corresponding between and within equations are

$$\bar{y}_i = \alpha + \bar{x}_i\beta_1 + \mathbf{s}_i\beta_2 + \bar{\mathbf{z}}\beta_3 + \nu_i + \bar{\epsilon}_i \quad (2'')$$

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{x}_i)\beta_1 + (\mathbf{z}_t - \bar{\mathbf{z}})\beta_3 + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3'')$$

In the between estimator of (2''), no estimate of β_3 is possible because $\bar{\mathbf{z}}$ is a constant across the i observations; the regression-estimated intercept will be an estimate of $\alpha + \bar{\mathbf{z}}\beta_3$. On the other hand, it can provide estimates of β_1 and β_2 . It can estimate effects of factors that are constant over time, such as race and sex, but to do so it must assume that ν_i is uncorrelated with those factors.

The within estimator of (3''), like the between estimator, provides an estimate of β_1 but provides no estimate of β_2 for time-invariant factors. Instead, it provides an estimate of β_3 , the effects of the time-varying factors. The within estimator can also provide estimates u_i for ν_i . More correctly, the estimator u_i is an estimator of $\nu_i + \mathbf{s}_i\beta_2$. Thus u_i is an estimator of ν_i only if there are no time-invariant variables in the model. If there are time-invariant variables, u_i is an estimate of ν_i plus the effects of the time-invariant variables.

Remarks are presented under the following headings:

Assessing goodness of fit
xtreg and associated commands

Assessing goodness of fit

R^2 is a popular measure of goodness of fit in ordinary regression. In our case, given $\hat{\alpha}$ and $\hat{\beta}$ estimates of α and β , we can assess the goodness of fit with respect to (1), (2), or (3). The prediction equations are, respectively,

$$\hat{y}_{it} = \hat{\alpha} + \mathbf{x}_{it}\hat{\beta} \quad (1''')$$

$$\hat{\bar{y}}_i = \hat{\alpha} + \bar{\mathbf{x}}_i\hat{\beta} \quad (2''')$$

$$\hat{\tilde{y}}_{it} = (\hat{y}_{it} - \hat{\bar{y}}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\hat{\beta} \quad (3''')$$

xtreg reports “ R -squares” corresponding to these three equations. R -squares is in quotes because the R -squares reported do not have all the properties of the OLS R^2 .

The ordinary properties of R^2 include being equal to the squared correlation between \hat{y} and y and being equal to the fraction of the variation in y explained by \hat{y} —formally defined as $\text{Var}(\hat{y})/\text{Var}(y)$. The identity of the definitions is from a special property of the OLS estimates; in general, given a prediction \hat{y} for y , the squared correlation is not equal to the ratio of the variances, and the ratio of the variances is not required to be less than 1.

xtreg reports R^2 values calculated as correlations squared, calling them R^2 overall, corresponding to (1'''); R^2 between, corresponding to (2'''); and R^2 within, corresponding to (3'''). In fact, you can think of each of these three numbers as having all the properties of ordinary R^2 s, if you bear in mind that the prediction being judged is not \hat{y}_{it} , $\hat{\bar{y}}_i$, and $\hat{\tilde{y}}_{it}$, but $\gamma_1\hat{y}_{it}$ from the regression $y_{it} = \gamma_1\hat{y}_{it}$; $\gamma_2\hat{\bar{y}}_i$ from the regression $\bar{y}_i = \gamma_2\hat{\bar{y}}_i$; and $\gamma_3\hat{\tilde{y}}_{it}$ from $\tilde{y}_{it} = \gamma_3\hat{\tilde{y}}_{it}$.

In particular, **xtreg**, **be** obtains its estimates by performing OLS on (2), and therefore its reported R^2 between is an ordinary R^2 . The other two reported R^2 s are merely correlations squared, or, if you prefer, R^2 s from the second-round regressions $y_{it} = \gamma_{11}\hat{y}_{it}$ and $\tilde{y}_{it} = \gamma_{13}\hat{\tilde{y}}_{it}$.

xtreg, **fe** obtains its estimates by performing OLS on (3), so its reported R^2 within is an ordinary R^2 . As with **be**, the other R^2 s are correlations squared, or, if you prefer, R^2 s from the second-round regressions $\bar{y}_i = \gamma_{22}\hat{\bar{y}}_i$ and, as with **be**, $\tilde{y}_{it} = \gamma_{23}\hat{\tilde{y}}_{it}$.

xtreg, **re** obtains its estimates by performing OLS on (4); none of the R^2 s corresponding to (1'''), (2'''), or (3''') correspond directly to this estimator (the “relevant” R^2 is the one corresponding to (4)). All three reported R^2 s are correlations squared, or, if you prefer, from second-round regressions.

xtreg and associated commands

➤ Example 1: Between-effects model

Using `nlswork.dta` described in [XT] `xt`, we will model `ln_wage` in terms of completed years of schooling (`grade`), current age and age squared, current years worked (`experience`) and `experience` squared, current years of tenure on the current job and `tenure` squared, whether black (`race = 2`), whether residing in an area not designated a standard metropolitan statistical area (SMSA), and whether residing in the South.

```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
```

To obtain the between-effects estimates, we use `xtreg, be`. `nlswork.dta` has previously been `xtset idcode year` because that is what is true of the data, but for running `xtreg`, it would have been sufficient to have `xtset idcode` by itself.

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, be

Between regression (regression on group means)   Number of obs       =      28091
Group variable: idcode                          Number of groups    =      4697

R-sq:  within = 0.1591                          Obs per group: min =         1
        between = 0.4900                          avg =         6.0
        overall = 0.3695                          max =        15

                                                F(10,4686)          =      450.23
                                                Prob > F              =      0.0000

sd(u_i + avg(e_i.))= .3036114
```

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	.0607602	.0020006	30.37	0.000	.0568382	.0646822
age	.0323158	.0087251	3.70	0.000	.0152105	.0494211
c.age#c.age	-.0005997	.0001429	-4.20	0.000	-.0008799	-.0003194
ttl_exp	.0138853	.0056749	2.45	0.014	.0027598	.0250108
c.ttl_exp#						
c.ttl_exp	.0007342	.0003267	2.25	0.025	.0000936	.0013747
tenure	.0698419	.0060729	11.50	0.000	.0579361	.0817476
c.tenure#						
c.tenure	-.0028756	.0004098	-7.02	0.000	-.0036789	-.0020722
race						
black	-.0564167	.0105131	-5.37	0.000	-.0770272	-.0358061
not_smsa	-.1860406	.0112495	-16.54	0.000	-.2080949	-.1639862
south	-.0993378	.010136	-9.80	0.000	-.1192091	-.0794665
_cons	.3339113	.1210434	2.76	0.006	.0966093	.5712133

The between-effects regression is estimated on person-averages, so the “`n = 4697`” result is relevant. `xtreg, be` reports the “number of observations” and group-size information: `describe` in [XT] `xt` showed that we have 28,534 “observations”—person-years, really—of data. If we take the subsample that has no missing values in `ln_wage`, `grade`, ..., `south` leaves us with 28,091 observations on person-years, reflecting 4,697 persons, each observed for an average of 6.0 years.

For goodness of fit, the R^2 between is directly relevant; our R^2 is 0.4900. If, however, we use these estimates to predict the within model, we have an R^2 of 0.1591. If we use these estimates to fit the overall data, our R^2 is 0.3695.

The F statistic tests that the coefficients on the regressors `grade`, `age`, `...`, `south` are all jointly zero. Our model is significant.

The root mean squared error of the fitted regression, which is an estimate of the standard deviation of $\nu_i + \bar{\epsilon}_i$, is 0.3036.

For our coefficients, each year of schooling increases hourly wages by 6.1%; age increases wages up to age 26.9 and thereafter decreases them (because the quadratic $ax^2 + bx + c$ turns over at $x = -b/2a$, which for our `age` and `c.age#c.age` coefficients is $0.0323158/(2 \times 0.0005997) \approx 26.9$); total experience increases wages at an increasing rate (which is surprising and bothersome); tenure on the current job increases wages up to a tenure of 12.1 years and thereafter decreases them; wages of blacks are, these things held constant, (approximately) 5.6% below that of nonblacks (approximately because `2.race` is an indicator variable); residing in a non-SMSA (rural area) reduces wages by 18.6%; and residing in the South reduces wages by 9.9%.

◀

► Example 2: Fixed-effects model

To fit the same model with the fixed-effects estimator, we specify the `fe` option.

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, fe
note: grade omitted because of collinearity
note: 2.race omitted because of collinearity

Fixed-effects (within) regression              Number of obs   =   28091
Group variable: idcode                        Number of groups  =    4697

R-sq:  within = 0.1727                        Obs per group: min =     1
        between = 0.3505                        avg           =    6.0
        overall = 0.2625                        max           =    15

                                           F(8,23386)       =   610.12
corr(u_i, Xb) = 0.1936                        Prob > F          =    0.0000
```

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	0 (omitted)					
age	.0359987	.0033864	10.63	0.000	.0293611	.0426362
c.age#c.age	-.000723	.0000533	-13.58	0.000	-.0008274	-.0006186
ttl_exp	.0334668	.0029653	11.29	0.000	.0276545	.039279
c.ttl_exp#c.ttl_exp	.0002163	.0001277	1.69	0.090	-.0000341	.0004666
tenure	.0357539	.0018487	19.34	0.000	.0321303	.0393775
c.tenure#c.tenure	-.0019701	.000125	-15.76	0.000	-.0022151	-.0017251
race						
black	0 (omitted)					
not_smsa	-.0890108	.0095316	-9.34	0.000	-.1076933	-.0703282
south	-.0606309	.0109319	-5.55	0.000	-.0820582	-.0392036
_cons	1.03732	.0485546	21.36	0.000	.9421496	1.13249
sigma_u	.35562203					
sigma_e	.29068923					
rho	.59946283	(fraction of variance due to u_i)				

F test that all u_i=0: F(4696, 23386) = 6.65 Prob > F = 0.0000

The observation summary at the top is the same as for the between-effects model, although this time it is the “Number of obs” that is relevant.

Our three R^2 s are not too different from those reported previously; the R^2 within is slightly higher (0.1727 versus 0.1591), and the R^2 between is a little lower (0.3505 versus 0.4900), as expected, because the between estimator maximizes R^2 between and the within estimator R^2 within. In terms of overall fit, these estimates are somewhat worse (0.2625 versus 0.3695).

`xtreg, fe` can estimate σ_ν and σ_ϵ , although how you interpret these estimates depends on whether you are using `xtreg` to fit a fixed-effects model or random-effects model. To clarify this fine point, in the fixed-effects model, ν_i are formally fixed—they have no distribution. If you subscribe to this view, think of the reported $\hat{\sigma}_\nu$ as merely an arithmetic way to describe the range of the estimated but fixed ν_i . If, however, you are using the fixed-effects estimator of the random-effects model, 0.355622 is an estimate of σ_ν or would be if there were no omitted variables.

Here both `grade` and `2.race` were omitted from the model because they do not vary over time. Because `grade` and `2.race` are time invariant, our estimate u_i is an estimate of ν_i plus the effects of `grade` and `2.race`, so our estimate of the standard deviation is based on the variation in ν_i , `grade`, and `2.race`. On the other hand, had `2.race` and `grade` been omitted merely because they were collinear with the other regressors in our model, u_i would be an estimate of ν_i , and 0.355622 would be an estimate of σ_ν . (`xtsum` and `xttab` allow you to determine whether a variable is time invariant; see [XT] `xtsum` and [XT] `xttab`.)

Regardless of the status of u_i , our estimate of the standard deviation of ϵ_{it} is valid (and, in fact, is the estimate that would be used by the random-effects estimator to produce its results).

Our estimate of the correlation of u_i with \mathbf{x}_{it} suffers from the problem of what u_i measures. We find correlation but cannot say whether this is correlation of ν_i with \mathbf{x}_{it} or merely correlation of `grade` and `2.race` with \mathbf{x}_{it} . In any case, the fixed-effects estimator is robust to such a correlation, and the other estimates it produces are unbiased.

So, although this estimator produces no estimates of the effects of `grade` and `2.race`, it does predict that age has a positive effect on wages up to age 24.9 years (compared with 26.9 years estimated by the between estimator); that total experience still increases wages at an increasing rate (which is still bothersome); that tenure increases wages up to 9.1 years (compared with 12.1); that living in a non-SMSA reduces wages by 8.9% (compared with a more drastic 18.6%); and that living in the South reduces wages by 6.1% (as compared with 9.9%).

◀

► Example 3: Fixed-effects models with robust standard errors

If we suspect that there is heteroskedasticity or within-panel serial correlation in the idiosyncratic error term ϵ_{it} , we could specify the `vce(robust)` option:


```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, fe vce(robust)
note: grade omitted because of collinearity
note: 2.race omitted because of collinearity
Fixed-effects (within) regression      Number of obs      =      28091
Group variable: idcode                 Number of groups    =      4697
R-sq:  within = 0.1727                  Obs per group: min =        1
      between = 0.3505                      avg =        6.0
      overall  = 0.2625                      max =       15
                                         F(8,4696)           =      273.86
corr(u_i, Xb) = 0.1936                  Prob > F             =      0.0000
                                         (Std. Err. adjusted for 4697 clusters in idcode)
```

ln_wage	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
grade	0	(omitted)				
age	.0359987	.0052407	6.87	0.000	.0257243	.046273
c.age#c.age	-.000723	.0000845	-8.56	0.000	-.0008887	-.0005573
ttl_exp	.0334668	.004069	8.22	0.000	.0254896	.0414439
c.ttl_exp#c.ttl_exp	.0002163	.0001763	1.23	0.220	-.0001294	.0005619
tenure	.0357539	.0024683	14.49	0.000	.0309148	.040593
c.tenure#c.tenure	-.0019701	.0001696	-11.62	0.000	-.0023026	-.0016376
race						
black	0	(omitted)				
not_smsa	-.0890108	.0137629	-6.47	0.000	-.1159926	-.062029
south	-.0606309	.0163366	-3.71	0.000	-.0926583	-.0286035
_cons	1.03732	.0739644	14.02	0.000	.8923149	1.182325
sigma_u	.35562203					
sigma_e	.29068923					
rho	.59946283	(fraction of variance due to u_i)				

Although the estimated coefficients are the same with and without the `vce(robust)` option, the robust estimator produced larger standard errors and a p -value for `c.ttl_exp#c.ttl_exp` above the conventional 10%. The F test of $\nu_i = 0$ is suppressed because it is too difficult to compute the robust form of the statistic when there are more than a few panels.

❑ Technical note

The robust standard errors reported above are identical to those obtained by clustering on the panel variable `idcode`. Clustering on the panel variable produces an estimator of the VCE that is robust to cross-sectional heteroskedasticity and within-panel (serial) correlation that is asymptotically equivalent to that proposed by [Arellano \(1987\)](#). Although the example above applies the fixed-effects estimator, the robust and cluster-robust VCE estimators are also available for the random-effects estimator. [Wooldridge \(2013\)](#) and [Arellano \(2003\)](#) discuss these robust and cluster-robust VCE estimators for the fixed-effects and random-effects estimators. More details are available in [Methods and formulas](#).

➤ **Example 4: Random-effects model**

Refitting our log-wage model with the random-effects estimator, we obtain

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, re theta

Random-effects GLS regression              Number of obs      =      28091
Group variable: idcode                    Number of groups     =       4697
R-sq:  within = 0.1715                    Obs per group: min   =         1
      between = 0.4784                      avg                =        6.0
      overall  = 0.3708                      max                =       15

corr(u_i, X) = 0 (assumed)                Wald chi2(10)        =    9244.74
                                           Prob > chi2          =     0.0000
```

		theta				
min	5%	median	95%	max		
0.2520	0.2520	0.5499	0.7016	0.7206		

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0646499	.0017812	36.30	0.000	.0611589	.0681409
age	.0368059	.0031195	11.80	0.000	.0306918	.0429201
c.age#c.age	-.0007133	.00005	-14.27	0.000	-.0008113	-.0006153
ttl_exp	.0290208	.002422	11.98	0.000	.0242739	.0337678
c.ttl_exp#c.ttl_exp	.0003049	.0001162	2.62	0.009	.000077	.0005327
tenure	.0392519	.0017554	22.36	0.000	.0358113	.0426925
c.tenure#c.tenure	-.0020035	.0001193	-16.80	0.000	-.0022373	-.0017697
race						
black	-.053053	.0099926	-5.31	0.000	-.0726381	-.0334679
not_smsa	-.1308252	.0071751	-18.23	0.000	-.1448881	-.1167622
south	-.0868922	.0073032	-11.90	0.000	-.1012062	-.0725781
_cons	.2387207	.049469	4.83	0.000	.1417633	.3356781
sigma_u	.25790526					
sigma_e	.29068923					
rho	.44045273	(fraction of variance due to u_i)				

According to the R^2 s, this estimator performs worse within than the within fixed-effects estimator and worse between than the between estimator, as it must, and slightly better overall.

We estimate that σ_ν is 0.2579 and σ_ϵ is 0.2907 and, by assertion, assume that the correlation of ν and \mathbf{x} is zero.

All that is known about the random-effects estimator is its asymptotic properties, so rather than reporting an F statistic for overall significance, `xtreg, re` reports a χ^2 . Taken jointly, our coefficients are significant.

`xtreg, re` also reports a summary of the distribution of θ_i , an ingredient in the estimation of (4). θ is not a constant here because we observe women for unequal periods.

We estimate that schooling has a rate of return of 6.5% (compared with 6.1% between and no estimate within); that the increase of wages with age turns around at 25.8 years (compared with 26.9 between and 24.9 within); that total experience yet again increases wages increasingly; that the effect

of job tenure turns around at 9.8 years (compared with 12.1 between and 9.1 within); that being black reduces wages by 5.3% (compared with 5.6% between and no estimate within); that living in a non-SMSA reduces wages 13.1% (compared with 18.6% between and 8.9% within); and that living in the South reduces wages 8.7% (compared with 9.9% between and 6.1% within).



► Example 5: Random-effects model fit using ML

We could also have fit this random-effects model with the maximum likelihood estimator:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, mle

Fitting constant-only model:
Iteration 0:   log likelihood = -13690.161
Iteration 1:   log likelihood = -12819.317
Iteration 2:   log likelihood = -12662.039
Iteration 3:   log likelihood = -12649.744
Iteration 4:   log likelihood = -12649.614
Iteration 5:   log likelihood = -12649.614

Fitting full model:
Iteration 0:   log likelihood = -8922.145
Iteration 1:   log likelihood = -8853.6409
Iteration 2:   log likelihood = -8853.4255
Iteration 3:   log likelihood = -8853.4254

Random-effects ML regression               Number of obs      =      28091
Group variable: idcode                     Number of groups   =       4697
Random effects u_i ~ Gaussian              Obs per group: min =         1
                                           avg   =         6.0
                                           max   =         15

                                           LR chi2(10)       =      7592.38
                                           Prob > chi2       =       0.0000

Log likelihood = -8853.4254
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0646093	.0017372	37.19	0.000	.0612044	.0680142
age	.0368531	.0031226	11.80	0.000	.030733	.0429732
c.age#c.age	-.0007132	.0000501	-14.24	0.000	-.0008113	-.000615
ttl_exp	.0288196	.0024143	11.94	0.000	.0240877	.0335515
c.ttl_exp#c.ttl_exp	.000309	.0001163	2.66	0.008	.0000811	.0005369
tenure	.0394371	.0017604	22.40	0.000	.0359868	.0428875
c.tenure#c.tenure	-.0020052	.0001195	-16.77	0.000	-.0022395	-.0017709
race						
black	-.0533394	.0097338	-5.48	0.000	-.0724172	-.0342615
not_smsa	-.1323433	.0071322	-18.56	0.000	-.1463221	-.1183644
south	-.0875599	.0072143	-12.14	0.000	-.1016998	-.0734201
_cons	.2390837	.0491902	4.86	0.000	.1426727	.3354947
/sigma_u	.2485556	.0035017			.2417863	.2555144
/sigma_e	.2918458	.001352			.289208	.2945076
rho	.4204033	.0074828			.4057959	.4351212

Likelihood-ratio test of sigma_u=0: chibar2(01)= 7339.84 Prob>=chibar2 = 0.000

The estimates are nearly the same as those produced by `xtreg, re`—the GLS estimator. For instance, `xtreg, re` estimated the coefficient on `grade` to be 0.0646499, `xtreg, mle` estimated 0.0646093, and the ratio is $0.0646499/0.0646093 = 1.001$ to three decimal places. Similarly, the standard errors are nearly equal: $0.0017811/0.0017372 = 1.025$. Below we compare all 11 coefficients:

Estimator	Coefficient ratio			SE ratio		
	mean	min.	max.	mean	min.	max.
<code>xtreg, mle (ML)</code>	1.	1.	1.	1.	1.	1.
<code>xtreg, re (GLS)</code>	.997	.987	1.007	1.006	.997	1.027



➤ **Example 6: Population-averaged model**

We could also have fit this model with the population-averaged estimator:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, pa

Iteration 1: tolerance = .0310561
Iteration 2: tolerance = .00074898
Iteration 3: tolerance = .0000147
Iteration 4: tolerance = 2.880e-07

GEE population-averaged model
Group variable:                idcode      Number of obs      =      28091
Link:                        identity      Number of groups     =      4697
Family:                      Gaussian      Obs per group: min   =           1
Correlation:                 exchangeable      avg              =          6.0
                                           max              =          15
                                           Wald chi2(10)       =    9598.89
Scale parameter:              .1436709      Prob > chi2          =      0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0645427	.0016829	38.35	0.000	.0612442	.0678412
age	.036932	.0031509	11.72	0.000	.0307564	.0431076
c.age#c.age	-.0007129	.0000506	-14.10	0.000	-.0008121	-.0006138
ttl_exp	.0284878	.0024169	11.79	0.000	.0237508	.0332248
c.ttl_exp#						
c.ttl_exp	.0003158	.0001172	2.69	0.007	.0000086	.0005456
tenure	.0397468	.0017779	22.36	0.000	.0362621	.0432315
c.tenure#						
c.tenure	-.002008	.0001209	-16.61	0.000	-.0022449	-.0017711
race						
black	-.0538314	.0094086	-5.72	0.000	-.072272	-.0353909
not_smsa	-.1347788	.0070543	-19.11	0.000	-.1486049	-.1209526
south	-.0885969	.0071132	-12.46	0.000	-.1025386	-.0746552
_cons	.2396286	.0491465	4.88	0.000	.1433034	.3359539

These results differ from those produced by `xtreg, re` and `xtreg, mle`. Coefficients are larger and standard errors smaller. `xtreg, pa` is simply another way to run the `xtgee` command. That is, we would have obtained the same output had we typed


```
. xtgee ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south
(output omitted because it is the same as above)
```

See [XT] [xtgee](#). In the language of [xtgee](#), the random-effects model corresponds to an exchangeable correlation structure and identity link, and [xtgee](#) also allows other correlation structures. Let's stay with the random-effects model, however. [xtgee](#) will also produce robust estimates of variance, and we refit this model that way by typing

```
. xtgee ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, vce(robust)
(output omitted, coefficients the same, standard errors different)
```

In the [previous example](#), we presented a table comparing [xtreg, re](#) with [xtreg, mle](#). Below we add the results from the estimates shown and the ones we did with [xtgee, vce\(robust\)](#):

Estimator		Coefficient ratio			SE ratio		
		mean	min.	max.	mean	min.	max.
xtreg, mle	(ML)	1.	1.	1.	1.	1.	1.
xtreg, re	(GLS)	.997	.987	1.007	1.006	.997	1.027
xtreg, pa	(PA)	1.060	.847	1.317	.853	.626	.986
xtgee, vce(robust)	(PA)	1.060	.847	1.317	1.306	.957	1.545

So, which are right? This is a real dataset, and we do not know. However, in [example 2](#) in [XT] [xtreg postestimation](#), we will present evidence that the assumptions underlying the [xtreg, re](#) and [xtreg, mle](#) results are not met.



Stored results

`xtreg`, `re` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if T is constant
<code>e(sigma)</code>	ancillary parameter (γ , \lnormal)
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(r2_w)</code>	R -squared for within model
<code>e(r2_o)</code>	R -squared for overall model
<code>e(r2_b)</code>	R -squared for between model
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	χ^2
<code>e(p)</code>	significance
<code>e(rho)</code>	ρ
<code>e(thta_min)</code>	minimum θ
<code>e(thta_5)</code>	θ , 5th percentile
<code>e(thta_50)</code>	θ , 50th percentile
<code>e(thta_95)</code>	θ , 95th percentile
<code>e(thta_max)</code>	maximum θ
<code>e(rmse)</code>	root mean squared error of GLS regression
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	<code>xtreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(clustvar)</code>	name of cluster variable
<code>e(chi2type)</code>	Wald; type of model χ^2 test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(sa)</code>	Swamy–Arora estimator of the variance components (<code>sa</code> only)
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(bf)</code>	coefficient vector for fixed-effects model
<code>e(theta)</code>	θ
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(VCEf)</code>	VCE for fixed-effects model

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

xtreg, be stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(typ)</code>	WLS, if <code>wls</code> specified
<code>e(mss)</code>	model sum of squares
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if T is constant
<code>e(r2)</code>	R -squared
<code>e(r2_a)</code>	adjusted R -squared
<code>e(r2_w)</code>	R -squared for within model
<code>e(r2_o)</code>	R -squared for overall model
<code>e(r2_b)</code>	R -squared for between model
<code>e(F)</code>	F statistic
<code>e(rmse)</code>	root mean squared error
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

Macros

<code>e(cmd)</code>	xtreg
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	be
<code>e(title)</code>	title in estimation output
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by margins
<code>e(marginsnotok)</code>	predictions disallowed by margins
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

xtreg, **fe** stores the following in **e()**:

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(mss)	model sum of squares
e(df_m)	model degrees of freedom
e(rss)	residual sum of squares
e(df_r)	residual degrees of freedom
e(tss)	total sum of squares
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(Tcon)	1 if T is constant
e(sigma)	ancillary parameter (γ , \lnormal)
e(corr)	$\text{corr}(u_i, Xb)$
e(sigma_u)	panel-level standard deviation
e(sigma_e)	standard deviation of ϵ_{it}
e(r2)	R -squared
e(r2_a)	adjusted R -squared
e(r2_w)	R -squared for within model
e(r2_o)	R -squared for overall model
e(r2_b)	R -squared for between model
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(N_clust)	number of clusters
e(rho)	ρ
e(F)	F statistic
e(F_f)	F for $u_i=0$
e(df_a)	degrees of freedom for absorbed effect
e(df_b)	numerator degrees of freedom for F statistic
e(rmse)	root mean squared error
e(Tbar)	harmonic mean of group sizes
e(rank)	rank of e(V)

Macros

e(cmd)	xtreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	fe
e(wtype)	weight type
e(wexp)	weight expression
e(clustvar)	name of cluster variable
e(vce)	<i>vcetype</i> specified in vce()
e(vcetype)	title used to label Std. Err.
e(properties)	b V
e(predict)	program used to implement predict
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
------------------	-------------------------

xtreg, mle stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(sigma_u)	panel-level standard deviation
e(sigma_e)	standard deviation of ϵ_{it}
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(ll_c)	log likelihood, comparison model
e(chi2)	χ^2
e(chi2_c)	χ^2 for comparison test
e(rho)	ρ
e(rank)	rank of e(V)

Macros

e(cmd)	xtreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	ml
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(vce)	vcetype specified in vce()
e(vcetype)	title used to label Std. Err.
e(chi2type)	Wald or LR; type of model χ^2 test
e(chi2_ct)	Wald or LR; type of model χ^2 test corresponding to e(chi2_c)
e(distrib)	Gaussian; the distribution of the RE
e(properties)	b V
e(predict)	program used to implement predict
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
-----------	-------------------------

xtreg, **pa** stores the following in **e()**:

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(chi2)	χ^2
e(p)	significance
e(df_pear)	degrees of freedom for Pearson χ^2
e(chi2_dev)	χ^2 test of deviance
e(chi2_dis)	χ^2 test of deviance dispersion
e(deviance)	deviance
e(dispers)	deviance dispersion
e(phi)	scale parameter
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(rank)	rank of e(V)
e(tol)	target tolerance
e(dif)	achieved tolerance
e(rc)	return code

Macros

e(cmd)	xtgee
e(cmd2)	xtreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(model)	pa
e(family)	Gaussian
e(link)	identity; link function
e(corr)	correlation structure
e(scale)	x2, dev, phi, or #, scale parameter
e(wtype)	weight type
e(wexp)	weight expression
e(offset)	linear offset variable
e(chi2type)	Wald; type of model χ^2 test
e(vce)	<i>vce</i> type specified in vce()
e(vctype)	title used to label Std. Err.
e(rgf)	rgf , if rgf specified
e(nmp)	nmp , if specified
e(properties)	b V
e(predict)	program used to implement predict
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(R)	estimated working correlation matrix
e(V)	variance-covariance matrix of the estimators
e(V_modelbased)	model-based variance

Functions

e(sample)	marks estimation sample
------------------	-------------------------

Methods and formulas

The model to be fit is

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it}$$

for $i = 1, \dots, n$ and, for each i , $t = 1, \dots, T$, of which T_i periods are actually observed.

Methods and formulas are presented under the following headings:

[xtreg, fe](#)
[xtreg, be](#)
[xtreg, re](#)
[xtreg, mle](#)
[xtreg, pa](#)

xtreg, fe

`xtreg, fe` produces estimates by running OLS on

$$(y_{it} - \bar{y}_i + \bar{\bar{y}}) = \alpha + (\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\bar{\mathbf{x}}})\beta + (\epsilon_{it} - \bar{\epsilon}_i + \bar{\bar{\nu}}) + \bar{\bar{\epsilon}}$$

where $\bar{y}_i = \sum_{t=1}^{T_i} y_{it}/T_i$, and similarly, $\bar{\bar{y}} = \sum_i \sum_t y_{it}/(nT_i)$. The conventional covariance matrix of the estimators is adjusted for the extra $n - 1$ estimated means, so results are the same as using OLS on (1) to estimate ν_i directly. Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#), particularly [Introduction](#) and [Methods and formulas](#). Wooldridge (2013) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2013), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation induced by the within transform.

From the estimates $\hat{\alpha}$ and $\hat{\beta}$, estimates u_i of ν_i are obtained as $u_i = \bar{y}_i - \hat{\alpha} - \bar{\mathbf{x}}_i\hat{\beta}$. Reported from the calculated u_i are its standard deviation and its correlation with $\bar{\mathbf{x}}_i\hat{\beta}$. Reported as the standard deviation of e_{it} is the regression's estimated root mean squared error, s , which is adjusted (as previously stated) for the $n - 1$ estimated means.

Reported as R^2 within is the R^2 from the mean-deviated regression.

Reported as R^2 between is $\text{corr}(\bar{\mathbf{x}}_i\hat{\beta}, \bar{y}_i)^2$.

Reported as R^2 overall is $\text{corr}(\mathbf{x}_{it}\hat{\beta}, y_{it})^2$.

xtreg, be

`xtreg, be` fits the following model:

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i\beta + \nu_i + \bar{\epsilon}_i$$

Estimation is via OLS unless T_i is not constant and the `wls` option is specified. Otherwise, the estimation is performed via WLS. The estimates and conventional VCE are obtained from `regress` for both cases, but for WLS, `[aweight=T_i]` is specified.

Reported as R^2 between is the R^2 from the fitted regression.

Reported as R^2 within is $\text{corr}\{(\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\hat{\beta}, y_{it} - \bar{y}_i\}^2$.

Reported as R^2 overall is $\text{corr}(\mathbf{x}_{it}\hat{\beta}, y_{it})^2$.

xtnreg, re

The key to the random-effects estimator is the GLS transform. Given estimates of the idiosyncratic component, $\hat{\sigma}_e^2$, and the individual component, $\hat{\sigma}_u^2$, the GLS transform of a variable z for the random-effects model is

$$z_{it}^* = z_{it} - \hat{\theta}_i \bar{z}_i$$

where $\bar{z}_i = \frac{1}{T_i} \sum_t^{T_i} z_{it}$ and

$$\hat{\theta}_i = 1 - \sqrt{\frac{\hat{\sigma}_e^2}{T_i \hat{\sigma}_u^2 + \hat{\sigma}_e^2}}$$

Given an estimate of $\hat{\theta}_i$, one transforms the dependent and independent variables, and then the coefficient estimates and the conventional variance–covariance matrix come from an OLS regression of y_{it}^* on \mathbf{x}_{it}^* and the transformed constant $1 - \hat{\theta}_i$. Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [_robust](#); in particular, see [Introduction](#) and [Methods and formulas](#). [Wooldridge \(2013\)](#) and [Arellano \(2003\)](#) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by [Wooldridge \(2013\)](#), [Stock and Watson \(2008\)](#), and [Arellano \(2003\)](#), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in ϵ_{it} .

The cluster–robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

Stata has two implementations of the Swamy–Arora method for estimating the variance components. They produce the same results in balanced panels and share the same estimator of σ_e^2 . However, the two methods differ in their estimator of σ_u^2 in unbalanced panels. We call the first $\hat{\sigma}_{u\overline{T}}^2$ and the second $\hat{\sigma}_{uSA}^2$. Both estimators are consistent; however, $\hat{\sigma}_{uSA}^2$ has a more elaborate adjustment for small samples than $\hat{\sigma}_{u\overline{T}}^2$. (See [Baltagi \[2013\]](#), [Baltagi and Chang \[1994\]](#), and [Swamy and Arora \[1972\]](#) for derivations of these methods.)

Both methods use the same function of within residuals to estimate the idiosyncratic error component σ_e . Specifically,

$$\hat{\sigma}_e^2 = \frac{\sum_i^n \sum_t^{T_i} e_{it}^2}{N - n - K + 1}$$

where

$$e_{it} = (y_{it} - \bar{y}_i + \bar{\bar{y}}) - \hat{\alpha}_w - (\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\bar{\mathbf{x}}})\hat{\beta}_w$$

and $\hat{\alpha}_w$ and $\hat{\beta}_w$ are the within estimates of the coefficients and $N = \sum_i^n T_i$. After passing the within residuals through the within transform, only the idiosyncratic errors are left.

The default method for estimating σ_u^2 is

$$\hat{\sigma}_{u\bar{T}}^2 = \max \left\{ 0, \frac{SSR_b}{n - K} - \frac{\hat{\sigma}_e^2}{\bar{T}} \right\}$$

where

$$SSR_b = \sum_i^n \left(\bar{y}_i - \hat{\alpha}_b - \bar{x}_i \hat{\beta}_b \right)^2$$

$\hat{\alpha}_b$ and $\hat{\beta}_b$ are coefficient estimates from the between regression and \bar{T} is the harmonic mean of T_i :

$$\bar{T} = \frac{n}{\sum_i^n \frac{1}{T_i}}$$

This estimator is consistent for σ_u^2 and is computationally less expensive than the second method. The sum of squared residuals from the between model estimate a function of both the idiosyncratic component and the individual component. Using our estimator of σ_e^2 , we can remove the idiosyncratic component, leaving only the desired individual component.

The second method is the Swamy–Arora method for unbalanced panels derived by [Baltagi and Chang \(1994\)](#), which has a more precise small-sample adjustment. Using this method,

$$\hat{\sigma}_{uSA}^2 = \max \left\{ 0, \frac{SSR_b - (n - K)\hat{\sigma}_e^2}{N - tr} \right\}$$

where

$$tr = \text{trace} \{ (\mathbf{X}'\mathbf{P}\mathbf{X})^{-1} \mathbf{X}'\mathbf{Z}\mathbf{Z}'\mathbf{X} \}$$

$$\mathbf{P} = \text{diag} \left\{ \left(\frac{1}{T_i} \right) \boldsymbol{\nu}_{T_i} \boldsymbol{\nu}_{T_i}' \right\}$$

$$\mathbf{Z} = \text{diag} [\boldsymbol{\nu}_{T_i}]$$

\mathbf{X} is the $N \times K$ matrix of covariates, including the constant, and $\boldsymbol{\nu}_{T_i}$ is a $T_i \times 1$ vector of ones.

The estimated coefficients $(\hat{\alpha}_r, \hat{\beta}_r)$ and their covariance matrix \mathbf{V}_r are reported together with the previously calculated quantities $\hat{\sigma}_e$ and $\hat{\sigma}_u$. The standard deviation of $\nu_i + e_{it}$ is calculated as $\sqrt{\hat{\sigma}_e^2 + \hat{\sigma}_u^2}$.

Reported as R^2 between is $\text{corr}(\bar{x}_i \hat{\beta}, \bar{y}_i)^2$.

Reported as R^2 within is $\text{corr}\{(\mathbf{x}_{it} - \bar{x}_i) \hat{\beta}, y_{it} - \bar{y}_i\}^2$.

Reported as R^2 overall is $\text{corr}(\mathbf{x}_{it} \hat{\beta}, y_{it})^2$.

xtreg, mle

The log likelihood for the i th unit is

$$l_i = -\frac{1}{2} \left(\frac{1}{\sigma_e^2} \left[\sum_{t=1}^{T_i} (y_{it} - \mathbf{x}_{it}\beta)^2 - \frac{\sigma_u^2}{T_i\sigma_u^2 + \sigma_e^2} \left\{ \sum_{t=1}^{T_i} (y_{it} - \mathbf{x}_{it}\beta) \right\}^2 \right] \right. \\ \left. + \ln \left(T_i \frac{\sigma_u^2}{\sigma_e^2} + 1 \right) + T_i \ln(2\pi\sigma_e^2) \right)$$

The `mle` and `re` options yield essentially the same results, except when total $N = \sum_i T_i$ is small (200 or less) and the data are unbalanced.

xtreg, pa

See [XT] [xtgee](#) for details on the methods and formulas used to calculate the population-averaged model using a generalized estimating equations approach.

Acknowledgments

We thank Richard Goldstein, who wrote the first draft of the routine that fits random-effects regressions, Badi Baltagi of the Department of Economics at Syracuse University, and Manuelita Ureta of the Department of Economics at Texas A&M University, who assisted us in working our way through the literature.

References

- Allison, P. D. 2009. *Fixed Effects Regression Models*. Newbury Park, CA: Sage.
- Andrews, M. J., T. Schank, and R. Upward. 2006. [Practical fixed-effects estimation methods for the three-way error-components model](#). *Stata Journal* 6: 461–481.
- Arellano, M. 1987. Computing robust standard errors for within-groups estimators. *Oxford Bulletin of Economics and Statistics* 49: 431–434.
- . 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Baltagi, B. H. 1985. Pooling cross-sections with unequal time-series lengths. *Economics Letters* 18: 133–136.
- . 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Baltagi, B. H., and Y.-J. Chang. 1994. Incomplete panels: A comparative study of alternative estimators for the unbalanced one-way error component regression model. *Journal of Econometrics* 62: 67–89.
- Baum, C. F. 2001. [Residual diagnostics for cross-section time series regression models](#). *Stata Journal* 1: 101–104.
- Blackwell, J. L., III. 2005. [Estimation and testing of fixed-effect panel-data systems](#). *Stata Journal* 5: 202–207.
- Bottai, M., and N. Orsini. 2004. [Confidence intervals for the variance component of random-effects linear models](#). *Stata Journal* 4: 429–435.
- Bruno, G. S. F. 2005. [Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals](#). *Stata Journal* 5: 473–500.
- De Hoyos, R. E., and V. Sarafidis. 2006. [Testing for cross-sectional dependence in panel-data models](#). *Stata Journal* 6: 482–496.
- Dwyer, J. H., and M. Feinleib. 1992. Introduction to statistical models for longitudinal observation. In *Statistical Models for Longitudinal Studies of Health*, ed. J. H. Dwyer, M. Feinleib, P. Lippert, and H. Hoffmeister, 3–48. New York: Oxford University Press.

- Greene, W. H. 1983. Simultaneous estimation of factor substitution, economies of scale, and non-neutral technical change. In *Econometric Analyses of Productivity*, ed. A. Dogramaci, 121–144. Boston: Kluwer.
- . 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.
- Hoechle, D. 2007. Robust standard errors for panel regressions with cross-sectional dependence. *Stata Journal* 7: 281–312.
- Judge, G. G., W. E. Griffiths, R. C. Hill, H. Lütkepohl, and T.-C. Lee. 1985. *The Theory and Practice of Econometrics*. 2nd ed. New York: Wiley.
- Lee, L. F., and W. E. Griffiths. 1979. The prior likelihood and best linear unbiased prediction in stochastic coefficient linear models. Working paper 1, Department of Econometrics, Armidale, Australia: University of New England.
- Libois, F., and V. Verardi. 2013. Semiparametric fixed-effects estimator. *Stata Journal* 13: 329–336.
- McCaffrey, D. F., K. Mihaly, J. R. Lockwood, and T. R. Sass. 2012. A review of Stata commands for fixed-effects estimation in normal linear models. *Stata Journal* 12: 406–432.
- Nichols, A. 2007. Causal inference with observational data. *Stata Journal* 7: 507–541.
- Rabe-Hesketh, S., A. Pickles, and C. Taylor. 2000. sg129: Generalized linear latent and mixed models. *Stata Technical Bulletin* 53: 47–57. Reprinted in *Stata Technical Bulletin Reprints*, vol. 9, pp. 293–307. College Station, TX: Stata Press.
- Schunck, R. 2013. Within and between estimates in random-effects models: Advantages and drawbacks of correlated random effects and hybrid models. *Stata Journal* 13: 65–76.
- Sosa-Escudero, W., and A. K. Bera. 2001. sg164: Specification tests for linear panel data models. *Stata Technical Bulletin* 61: 18–21. Reprinted in *Stata Technical Bulletin Reprints*, vol. 10, pp. 307–311. College Station, TX: Stata Press.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Swamy, P. A. V. B., and S. S. Arora. 1972. The exact finite sample properties of the estimators of coefficients in the error components regression models. *Econometrica* 40: 261–275.
- Taub, A. J. 1979. Prediction in the context of the variance-components model. *Journal of Econometrics* 10: 103–107.
- Twisk, J. W. R. 2013. *Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide*. 2nd ed. Cambridge: Cambridge University Press.
- Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western.

Also see

- [XT] **xtreg postestimation** — Postestimation tools for xtreg
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtgls** — Fit panel-data models by using GLS
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [ME] **mixed** — Multilevel mixed-effects linear regression
- [MI] **estimation** — Estimation commands for use with mi estimate
- [R] **areg** — Linear regression with a large dummy-variable set
- [R] **regress** — Linear regression
- [TS] **forecast** — Econometric model forecasting
- [TS] **prais** — Prais–Winsten and Cochrane–Orcutt regression
- [U] **20 Estimation and postestimation commands**

Description	Syntax for predict	Menu for predict	Options for predict
Syntax for xttest0	Menu for xttest0	Remarks and examples	Methods and formulas
References	Also see		

Description

The following postestimation commands are of special interest after `xtreg`:

Command	Description
<code>xttest0</code>	Breusch and Pagan LM test for random effects

The following standard postestimation commands are also available:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code> ²	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtreg` with the `be`, `pa`, or `re` option.

² `forecast` is not appropriate with `mi` estimation results.

Special-interest postestimation commands

xttest0, for use after xtreg, re, presents the Breusch and Pagan (1980) Lagrange multiplier test for random effects, a test that $\text{Var}(\nu_i) = 0$.

Syntax for predict

For all but the population-averaged model

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

Population-averaged model

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

statistic	Description
Main	
xb	$\mathbf{x}_j\mathbf{b}$, fitted values; the default
stdp	standard error of the fitted values
ue	$u_i + e_{it}$, the combined residual
*xbu	$\mathbf{x}_j\mathbf{b} + u_i$, prediction including effect
*u	u_i , the fixed- or random-error component
*e	e_{it} , the overall error component

Unstarred statistics are available both in and out of sample; type predict ... if e(sample) ... if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when if e(sample) is not specified.

PA_statistic	Description
Main	
mu	probability of <i>depvar</i> ; considers the offset()
rate	probability of <i>depvar</i>
xb	linear prediction
stdp	standard error of the linear prediction
score	first derivative of the log likelihood with respect to $\mathbf{x}_j\beta$

These statistics are available both in and out of sample; type predict ... if e(sample) ... if wanted only for the estimation sample.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb calculates the linear prediction, that is, $a + \mathbf{b}\mathbf{x}_{it}$. This is the default for all except the population-averaged model.

`stdp` calculates the standard error of the linear prediction. For the fixed-effects model, this excludes the variance due to uncertainty about the estimate of u_i .

`mu` and `rate` both calculate the predicted probability of *depvar*. `mu` takes into account the `offset()`, and `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.

`ue` calculates the prediction of $u_i + e_{it}$.

`xbu` calculates the prediction of $a + \mathbf{b}x_{it} + u_i$, the prediction including the fixed or random component.

`u` calculates the prediction of u_i , the estimated fixed or random effect.

`e` calculates the prediction of e_{it} .

`score` calculates the equation-level score, $u_j = \partial \ln L_j(\mathbf{x}_j\boldsymbol{\beta}) / \partial (\mathbf{x}_j\boldsymbol{\beta})$.

`nooffset` is relevant only if you specified `offset(varname)` for `xtreg, pa`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\mathbf{b}$ rather than $\mathbf{x}_{it}\mathbf{b} + \text{offset}_{it}$.

Syntax for `xttest0`

`xttest0`

Menu for `xttest0`

Statistics > Longitudinal/panel data > Linear models > Lagrange multiplier test for random effects

Remarks and examples

► Example 1

Continuing with our `xtreg, re` estimation example (example 4) in `xtreg`, we can see that `xttest0` will report a test of $\nu_i = 0$. In case we have any doubts, we could type

```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, re theta
(output omitted)

. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects

ln_wage[idcode,t] = Xb + u[idcode] + e[idcode,t]
Estimated results:

```

	Var	sd = sqrt(Var)
ln_wage	.2283326	.4778416
e	.0845002	.2906892
u	.0665151	.2579053

```
Test: Var(u) = 0
      chibar2(01) = 14779.98
      Prob > chibar2 = 0.0000
```


► Example 2

More importantly, after `xtreg, re` estimation, `hausman` will perform the Hausman specification test. If our model is correctly specified, and if ν_i is uncorrelated with \mathbf{x}_{it} , the (subset of) coefficients that are estimated by the fixed-effects estimator and the same coefficients that are estimated here should not statistically differ:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, re
(output omitted)

. estimates store random_effects

. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, fe
(output omitted)

. hausman . random_effects
```

	Coefficients		(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	(b) .	(B) random_eff~s		
age	.0359987	.0368059	-.0008073	.0013177
c.age#c.age	-.000723	-.0007133	-9.68e-06	.0000184
ttl_exp	.0334668	.0290208	.0044459	.001711
c.ttl_exp#c.tenure	.0002163	.0003049	-.0000886	.000053
c.tenure#c.race	.0357539	.0392519	-.003498	.0005797
not_smsa	-.0019701	-.0020035	.0000334	.0000373
south	-.0890108	-.1308252	.0418144	.0062745
	-.0606309	-.0868922	.0262613	.0081345

```

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic
      chi2(8) = (b-B)'[(V_b-V_B)^(-1)](b-B)
              =      149.43
      Prob>chi2 =      0.0000

```

We can reject the hypothesis that the coefficients are the same. Before turning to what this means, note that `hausman` listed the coefficients estimated by the two models. It did not, however, list `grade` and `2.race`. `hausman` did not make a mistake; in the Hausman test, we compare only the coefficients estimated by both techniques.

What does this mean? We have an unpleasant choice: we can admit that our model is misspecified—that we have not parameterized it correctly—or we can hold that our specification is correct, in which case the observed differences must be due to the zero correlation of ν_i and the \mathbf{x}_{it} assumption.

◀

□ Technical note

We can also mechanically explore the underpinnings of the test's dissatisfaction. In the comparison table from `hausman`, it is the coefficients on `not_smsa` and `south` that exhibit the largest differences. In [equation \(1'\)](#) of [XT] `xtreg`, we showed how to decompose a model into within and between effects. Let's do that with these two variables, assuming that changes in the average have one effect, whereas transitional changes have another:


```
. egen avgnsmsa = mean(not_smsa), by(id)
. generate devnsma = not_smsa -avgnsmsa
(8 missing values generated)
. egen avgsouth = mean(south), by(id)
. generate devsouth = south - avgsouth
(8 missing values generated)

. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure c.tenure#
> c.tenure 2.race avgnsm devnsm avgsou devsou
Random-effects GLS regression                Number of obs      =      28091
Group variable: idcode                      Number of groups   =      4697
R-sq:   within  = 0.1723                    Obs per group: min =         1
        between = 0.4809                      avg               =        6.0
        overall  = 0.3737                      max               =       15

                                           Wald chi2(12)      =    9319.56
corr(u_i, X)  = 0 (assumed)                  Prob > chi2        =     0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0631716	.0017903	35.29	0.000	.0596627	.0666805
age	.0375196	.0031186	12.03	0.000	.0314072	.043632
c.age#c.age	-.0007248	.00005	-14.50	0.000	-.0008228	-.0006269
ttl_exp	.0286543	.0024207	11.84	0.000	.0239098	.0333989
c.ttl_exp# c.ttl_exp	.0003222	.0001162	2.77	0.006	.0000945	.0005499
tenure	.0394423	.001754	22.49	0.000	.0360044	.0428801
c.tenure# c.tenure	-.0020081	.0001192	-16.85	0.000	-.0022417	-.0017746
race						
black	-.0545936	.0102101	-5.35	0.000	-.074605	-.0345821
avgnsmsa	-.1833237	.0109339	-16.77	0.000	-.2047537	-.1618937
devnsma	-.0887596	.0095071	-9.34	0.000	-.1073931	-.070126
avgsouth	-.1011235	.0098789	-10.24	0.000	-.1204858	-.0817611
devsouth	-.0598538	.0109054	-5.49	0.000	-.081228	-.0384797
_cons	.2682987	.0495778	5.41	0.000	.171128	.3654694
sigma_u	.2579182					
sigma_e	.29068923					
rho	.44047745	(fraction of variance due to u_i)				

We will leave the reinterpretation of this model to you, except that if we were really going to sell this model, we would have to explain why the between and within effects are different. Focusing on residence in a non-SMSA, we might tell a story about rural people being paid less and continuing to get paid less when they move to the SMSA. Given our panel data, we could create variables to measure this (an indicator for moved from non-SMSA to SMSA) and to measure the effects. In our assessment of this model, we should think about women in the cities moving to the country and their relative productivity in a bucolic setting.

In any case, the Hausman test now is

```
. estimates store new_random_effects
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race avgnsml devnsml avgsou devsou, fe
(output omitted)
. hausman . new_random_effects
```

	Coefficients			
	(b)	(B)	(b-B)	sqrt(diag(V_b-V_B))
	.	new_random~s	Difference	S.E.
age	.0359987	.0375196	-.0015209	.0013198
c.age#c.age	-.000723	-.0007248	1.84e-06	.0000184
ttl_exp	.0334668	.0286543	.0048124	.0017127
c.ttl_exp#c.ttl_exp	.0002163	.0003222	-.0001059	.0000531
tenure	.0357539	.0394423	-.0036884	.0005839
c.tenure#c.tenure	-.0019701	-.0020081	.000038	.0000377
devnsml	-.0890108	-.0887596	-.0002512	.000683
devsou	-.0606309	-.0598538	-.0007771	.0007618

```

      b = consistent under Ho and Ha; obtained from xtreg
      B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic
      chi2(8) = (b-B)'[(V_b-V_B)^(-1)](b-B)
              =          92.52
      Prob>chi2 =          0.0000

```

We have mechanically succeeded in greatly reducing the χ^2 , but not by enough. The major differences now are in the age, experience, and tenure effects. We already knew this problem existed because of the ever-increasing effect of experience. More careful parameterization work rather than simply including squares needs to be done.

□

Methods and formulas

`xttest0` reports the Lagrange multiplier test for random effects developed by [Breusch and Pagan \(1980\)](#) and as modified by [Baltagi and Li \(1990\)](#). The model

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_{it}$$

is fit via OLS, and then the quantity

$$\lambda_{LM} = \frac{(n\bar{T})^2}{2} \left(\frac{A_1^2}{(\sum_i T_i^2) - n\bar{T}} \right)$$

is calculated, where

$$A_1 = 1 - \frac{\sum_{i=1}^n (\sum_{t=1}^{T_i} v_{it})^2}{\sum_i \sum_t v_{it}^2}$$

The Baltagi and Li modification allows for unbalanced data and reduces to the standard formula

$$\lambda_{\text{LM}} = \begin{cases} \frac{nT}{2(T-1)} \left\{ \frac{\sum_i (\sum_t v_{it})^2}{\sum_i \sum_t v_{it}^2} - 1 \right\}^2, & \hat{\sigma}_u^2 \geq 0 \\ 0, & \hat{\sigma}_u^2 < 0 \end{cases}$$

when $T_i = T$ (balanced data). Under the null hypothesis, λ_{LM} is distributed as a 50:50 mixture of a point mass at zero and $\chi^2(1)$.

References

- Baltagi, B. H., and Q. Li. 1990. A Lagrange multiplier test for the error components model with incomplete panels. *Econometric Reviews* 9: 103–107.
- Breusch, T. S., and A. R. Pagan. 1980. The Lagrange multiplier test and its applications to model specification in econometrics. *Review of Economic Studies* 47: 239–253.
- Hausman, J. A. 1978. Specification tests in econometrics. *Econometrica* 46: 1251–1271.
- Sosa-Escudero, W., and A. K. Bera. 2008. [Tests for unbalanced error-components models under local misspecification](#). *Stata Journal* 8: 68–78.
- Verbeke, G., and G. Molenberghs. 2003. The use of score tests for inference on variance components. *Biometrics* 59: 254–262.

Also see

[XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models

[U] **20 Estimation and postestimation commands**

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	Acknowledgment
References	Also see		

Syntax

GLS random-effects (RE) model

```
xtregar depvar [indepvars] [if] [in] [, re options]
```

Fixed-effects (FE) model

```
xtregar depvar [indepvars] [if] [in] [weight] , fe [options]
```

<i>options</i>	Description
Model	
<code>re</code>	use random-effects estimator; the default
<code>fe</code>	use fixed-effects estimator
<code>rhotype(<i>rhomethod</i>)</code>	specify method to compute autocorrelation; seldom used
<code>rhof(#)</code>	use # for ρ and do not estimate ρ
<code>twostep</code>	perform two-step estimate of correlation
Reporting	
<code>llevel(#)</code>	set confidence level; default is <code>llevel(95)</code>
<code>lbi</code>	perform Baltagi–Wu LBI test
<code>display_options</code>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.
indepvars may contain factor variables; see [U] 11.4.3 Factor variables.
depvar and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.
`by` and `statsby` are allowed; see [U] 11.1.10 Prefix commands.
`fweights` and `awweights` are allowed for the fixed-effects model with `rhotype(regress)` or `rhotype(freg)`, or with a fixed rho; see [U] 11.1.6 weight. Weights must be constant within panel.
`coeflegend` does not appear in the dialog box.
See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Linear models > Linear regression with AR(1) disturbance (FE, RE)

Description

xtregar fits cross-sectional time-series regression models when the disturbance term is first-order autoregressive. **xtregar** offers a within estimator for fixed-effects models and a GLS estimator for random-effects models. Consider the model

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} \quad i = 1, \dots, N; \quad t = 1, \dots, T_i \quad (1)$$

where

$$\epsilon_{it} = \rho\epsilon_{i,t-1} + \eta_{it} \quad (2)$$

and where $|\rho| < 1$ and η_{it} is independent and identically distributed (i.i.d.) with mean 0 and variance σ_η^2 . If ν_i are assumed to be fixed parameters, the model is a fixed-effects model. If ν_i are assumed to be realizations of an i.i.d. process with mean 0 and variance σ_ν^2 , it is a random-effects model. Whereas in the fixed-effects model, the ν_i may be correlated with the covariates \mathbf{x}_{it} , in the random-effects model the ν_i are assumed to be independent of the \mathbf{x}_{it} . On the other hand, any \mathbf{x}_{it} that do not vary over t are collinear with the ν_i and will be dropped from the fixed-effects model. In contrast, the random-effects model can accommodate covariates that are constant over time.

xtregar can accommodate unbalanced panels whose observations are unequally spaced over time. **xtregar** implements the methods derived in [Baltagi and Wu \(1999\)](#).

Options

Model

re requests the GLS estimator of the random-effects model, which is the default.

fe requests the within estimator of the fixed-effects model.

rhotype(*rhomethod*) allows the user to specify any of the following estimators of ρ :

dw	$\rho_{dw} = 1 - d/2$, where d is the Durbin–Watson d statistic
regress	$\rho_{reg} = \beta$ from the residual regression $\epsilon_t = \beta\epsilon_{t-1}$
freg	$\rho_{freg} = \beta$ from the residual regression $\epsilon_t = \beta\epsilon_{t+1}$
tscorr	$\rho_{tscorr} = \epsilon'\epsilon_{t-1}/\epsilon'\epsilon$, where ϵ is the vector of residuals and ϵ_{t-1} is the vector of lagged residuals
theil	$\rho_{theil} = \rho_{tscorr}(N - k)/N$
nagar	$\rho_{nagar} = (\rho_{dw}N^2 + k^2)/(N^2 - k^2)$
onestep	$\rho_{onestep} = (n/m_c)(\epsilon'\epsilon_{t-1}/\epsilon'\epsilon)$, where ϵ is the vector of residuals, n is the number of observations, and m_c is the number of consecutive pairs of residuals

dw is the default method. Except for **onestep**, the details of these methods are given in [\[TS\] prais](#). **prais** handles unequally spaced data. **onestep** is the one-step method proposed by [Baltagi and Wu \(1999\)](#). More details on this method are available below in [Methods and formulas](#).

rhof($\#$) specifies that the given number be used for ρ and that ρ not be estimated.

twostep requests that a two-step implementation of the *rhomethod* estimator of ρ be used. Unless a fixed value of ρ is specified, ρ is estimated by running **prais** on the de-meaned data. When **twostep** is specified, **prais** will stop on the first iteration after the equation is transformed by ρ —the two-step efficient estimator. Although it is customary to iterate these estimators to convergence, they are efficient at each step. When **twostep** is not specified, the FGLS process iterates to convergence as described in the [Methods and formulas](#) of [\[TS\] prais](#).

`level(#)`; see [R] [estimation options](#).

`lbi` requests that the Baltagi–Wu (1999) locally best invariant (LBI) test statistic that $\rho = 0$ and a modified version of the Bhargava, Franzini, and Narendranathan (1982) Durbin–Watson statistic be calculated and reported. The default is not to report them. p -values are not reported for either statistic. Although Bhargava, Franzini, and Narendranathan (1982) published critical values for their statistic, no tables are currently available for the Baltagi–Wu LBI. Baltagi and Wu (1999) derive a normalized version of their statistic, but this statistic cannot be computed for datasets of moderate size. You can also specify these options upon replay.

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `novlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [estimation options](#).

The following option is available with `xtregar` but is not shown in the dialog box:

`coeflegend`; see [R] [estimation options](#).

Remarks and examples

Remarks are presented under the following headings:

[Introduction](#)

[The fixed-effects model](#)

[The random-effects model](#)

Introduction

If you have not read [XT] [xt](#), please do so.

Consider a linear panel-data model described by (1) and (2). In the fixed-effects model, the ν_i are a set of fixed parameters to be estimated. Alternatively, the ν_i may be random and correlated with the other covariates, with inference conditional on the ν_i in the sample; see Mundlak (1978) and Hsiao (2003). In the random-effects model, also known as the variance-components model, the ν_i are assumed to be realizations of an i.i.d. process with mean 0 and variance σ_ν^2 . `xtregar` offers a within estimator for the fixed-effect model and the Baltagi–Wu (1999) GLS estimator of the random-effects model. The Baltagi–Wu (1999) GLS estimator extends the balanced panel estimator in Baltagi and Li (1991) to a case of exogenously unbalanced panels with unequally spaced observations. Both these estimators offer several estimators of ρ .

The data can be unbalanced and unequally spaced. Specifically, the dataset contains observations on individual i at times t_{ij} for $j = 1, \dots, n_i$. The difference $t_{ij} - t_{i,j-1}$ plays an integral role in the estimation techniques used by `xtregar`. For this reason, you must `xtset` your data before using `xtregar`. For instance, if you have quarterly data, the “time” difference between the third and fourth quarter must be 1 month, not 3.

The fixed-effects model

Let’s examine the fixed-effect model first. The basic approach is common to all fixed-effects models. The ν_i are treated as nuisance parameters. We use a transformation of the model that removes the nuisance parameters and leaves behind the parameters of interest in an estimable form. Subtracting the group means from (1) removes the ν_i from the model

$$y_{itij} - \bar{y}_i = (\bar{x}_{itij} - \bar{x}_i) \beta + \epsilon_{itij} - \bar{\epsilon}_i \tag{3}$$

where

$$\bar{y}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} y_{itij} \qquad \bar{x}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{itij} \qquad \bar{\epsilon}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \epsilon_{itij}$$

After the transformation, (3) is a linear AR(1) model, potentially with unequally spaced observations. (3) can be used to estimate ρ . Given an estimate of ρ , we must do a Cochrane–Orcutt transformation on each panel and then remove the within-panel means and add back the overall mean for each variable. OLS on the transformed data will produce the within estimates of α and β .

► **Example 1: Fixed-effects model**

Let’s use the Grunfeld investment dataset to illustrate how **xtregar** can be used to fit the fixed-effects model. This dataset contains information on 10 firms’ investment, market value, and the value of their capital stocks. The data were collected annually between 1935 and 1954. The following output shows that we have **xtset** our data and gives the results of running a fixed-effects model with investment as a function of market value and the capital stock.

```
. use http://www.stata-press.com/data/r13/grunfeld
. xtset
    panel variable:  company (strongly balanced)
    time variable:  year, 1935 to 1954
    delta:  1 year

. xtregar invest mvalue kstock, fe
FE (within) regression with AR(1) disturbances  Number of obs      =      190
Group variable: company                        Number of groups   =       10
R-sq:  within  = 0.5927                      Obs per group: min =       19
       between  = 0.7989                      avg              =      19.0
       overall  = 0.7904                      max              =       19
                                              F(2,178)          =     129.49
corr(u_i, Xb) = -0.0454                      Prob > F           =      0.0000
```

invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
mvalue	.0949999	.0091377	10.40	0.000	.0769677	.113032
kstock	.350161	.0293747	11.92	0.000	.2921935	.4081286
_cons	-63.22022	5.648271	-11.19	0.000	-74.36641	-52.07402
rho_ar	.67210608					
sigma_u	91.507609					
sigma_e	40.992469					
rho_fov	.8328647	(fraction of variance because of u_i)				

```
F test that all u_i=0:      F(9,178) =      11.53      Prob > F = 0.0000
```

Because there are 10 groups, the panel-by-panel Cochrane–Orcutt method decreases the number of available observations from 200 to 190. The above example used the default **dw** estimator of ρ . Using the **tscorr** estimator of ρ yields


```
. xtregar invest mvalue kstock, fe rhotype(tscorr)
```

FE (within) regression with AR(1) disturbances	Number of obs	=	190		
Group variable: company	Number of groups	=	10		
R-sq: within	=	0.6583	Obs per group: min	=	19
between	=	0.8024	avg	=	19.0
overall	=	0.7933	max	=	19
	F(2,178)	=	171.47		
corr(u_i, Xb)	=	-0.0709	Prob > F	=	0.0000

invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
mvalue	.0978364	.0096786	10.11	0.000	.0787369	.1169359
kstock	.346097	.0242248	14.29	0.000	.2982922	.3939018
_cons	-61.84403	6.621354	-9.34	0.000	-74.91049	-48.77758
rho_ar	.54131231					
sigma_u	90.893572					
sigma_e	41.592151					
rho_fov	.82686297	(fraction of variance because of u_i)				

F test that all u_i=0: F(9,178) = 19.73 Prob > F = 0.0000



□ Technical note

The `tscorr` estimator of ρ is bounded in $[-1, 1]$. The other estimators of ρ are not. In samples with short panels, the estimates of ρ produced by the other estimators of ρ may be outside $[-1, 1]$. If this happens, use the `tscorr` estimator. However, simulations have shown that the `tscorr` estimator is biased toward zero. `dw` is the default because it performs well in Monte Carlo simulations. In the example above, the estimate of ρ produced by `tscorr` is much smaller than the one produced by `dw`. □

▷ Example 2: Using `xtset`

`xtregar` will complain if you try to run `xtregar` on a dataset that has not been `xtset`:

```
. xtset, clear
. xtregar invest mvalue kstock, fe
must specify panelvar and timevar; use xtset
r(459);
```

You must `xtset` your data to ensure that `xtregar` understands the nature of your time variable. Suppose that our observations were taken quarterly instead of annually. We will get the same results with the quarterly variable `t2` that we did with the annual variable `year`.

```
. generate t = year - 1934
. generate t2 = tq(1934q4) + t
. format t2 %tq
```



```
. list year t2 in 1/5
```

	year	t2
1.	1935	1935q1
2.	1936	1935q2
3.	1937	1935q3
4.	1938	1935q4
5.	1939	1936q1

```
. xtset company t2
    panel variable:  company (strongly balanced)
    time variable:   t2, 1935q1 to 1939q4
                delta: 1 quarter
```

```
. xtregar invest mvalue kstock, fe
```

FE (within) regression with AR(1) disturbances

Group variable: company

R-sq: within = 0.5927
 between = 0.7989
 overall = 0.7904

Number of obs = 190
Number of groups = 10
Obs per group: min = 19
 avg = 19.0
 max = 19
F(2,178) = 129.49
Prob > F = 0.0000

corr(u_i, Xb) = -0.0454

invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
mvalue	.0949999	.0091377	10.40	0.000	.0769677	.113032
kstock	.350161	.0293747	11.92	0.000	.2921935	.4081286
_cons	-63.22022	5.648271	-11.19	0.000	-74.36641	-52.07402
rho_ar	.67210608	(fraction of variance because of u_i)				
sigma_u	91.507609					
sigma_e	40.992469					
rho_fov	.8328647					

F test that all u_i=0: F(9,178) = 11.53 Prob > F = 0.0000



In all the examples thus far, we have assumed that ϵ_{it} is first-order autoregressive. Testing the hypothesis of $\rho = 0$ in a first-order autoregressive process produces test statistics with extremely complicated distributions. [Bhargava, Franzini, and Narendranathan \(1982\)](#) extended the Durbin–Watson statistic to the case of balanced, equally spaced panel datasets. [Baltagi and Wu \(1999\)](#) modify their statistic to account for unbalanced panels with unequally spaced data. In the same article, [Baltagi and Wu \(1999\)](#) derive the locally best invariant test statistic of $\rho = 0$. Both these test statistics have extremely complicated distributions, although [Bhargava, Franzini, and Narendranathan \(1982\)](#) did publish some critical values in their article. Specifying the `lbi` option to `xtregar` causes Stata to calculate and report the modified Bhargava et al. Durbin–Watson and the Baltagi–Wu LBI.

➤ Example 3: Testing for autocorrelation

In this example, we calculate the modified Bhargava et al. Durbin–Watson statistic and the Baltagi–Wu LBI. We exclude periods 9 and 10 from the sample, thereby reproducing the results of [Baltagi and Wu \(1999, 822\)](#). p -values are not reported for either statistic. Although [Bhargava, Franzini, and Narendranathan \(1982\)](#) published critical values for their statistic, no tables are currently available for the Baltagi–Wu (LBI). [Baltagi and Wu \(1999\)](#) did derive a normalized version of their statistic, but this statistic cannot be computed for datasets of moderate size.


```
. xtregar invest mvalue kstock if year !=1934 & year !=1944, fe lbi
```

FE (within) regression with AR(1) disturbances	Number of obs	=	180
Group variable: company	Number of groups	=	10
R-sq: within	=	0.5954	Obs per group: min = 18
between	=	0.7952	avg = 18.0
overall	=	0.7889	max = 18
	F(2,168)	=	123.63
corr(u_i, Xb)	=	-0.0516	Prob > F = 0.0000

invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
mvalue	.0941122	.0090926	10.35	0.000	.0761617	.1120627
kstock	.3535872	.0303562	11.65	0.000	.2936584	.4135161
_cons	-64.82534	5.946885	-10.90	0.000	-76.56559	-53.08509
rho_ar	.6697198					
sigma_u	93.320452					
sigma_e	41.580712					
rho_fov	.83435413	(fraction of variance because of u_i)				

F test that all u_i=0: F(9,168) = 11.55 Prob > F = 0.0000
 modified Bhargava et al. Durbin-Watson = .71380994
 Baltagi-Wu LBI = 1.0134522

◀

The random-effects model

In the random-effects model, the ν_i are assumed to be realizations of an i.i.d. process with mean 0 and variance σ_ν^2 . Furthermore, the ν_i are assumed to be independent of both the ϵ_{it} and the covariates \mathbf{x}_{it} . The latter of these assumptions can be strong, but inference is not conditional on the particular realizations of the ν_i in the sample. See [Mundlak \(1978\)](#) for a discussion of this point.

► Example 4: Random-effects model

By specifying the `re` option, we obtain the Baltagi–Wu GLS estimator of the random-effects model. This estimator can accommodate unbalanced panels and unequally spaced data. We run this model on the Grunfeld dataset:


```
. xtregar invest mvalue kstock if year !=1934 & year !=1944, re lbi
RE GLS regression with AR(1) disturbances      Number of obs      =      190
Group variable: company                       Number of groups   =       10
R-sq:  within = 0.7707                        Obs per group: min =       19
        between = 0.8039                      avg              =     19.0
        overall = 0.7958                      max              =       19
                                                Wald chi2(3)       =     351.37
corr(u_i, Xb) = 0 (assumed)                   Prob > chi2        =      0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mvalue	.0947714	.0083691	11.32	0.000	.0783683	.1111746
kstock	.3223932	.0263226	12.25	0.000	.2708019	.3739845
_cons	-45.21427	27.12492	-1.67	0.096	-98.37814	7.949603
rho_ar	.6697198	(estimated autocorrelation coefficient)				
sigma_u	74.662876					
sigma_e	42.253042					
rho_fov	.75742494	(fraction of variance due to u_i)				
theta	.66973313					

modified Bhargava et al. Durbin-Watson = .71380994
Baltagi-Wu LBI = 1.0134522

The modified Bhargava et al. Durbin–Watson and the Baltagi–Wu LBI are the same as those reported for the fixed-effects model because the formulas for these statistics do not depend on fitting the fixed-effects model or the random-effects model.



Stored results

xtregar, re stores the following in e():

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(d1)	Bhargava et al. Durbin–Watson
e(LBI)	Baltagi–Wu LBI statistic
e(N_LBI)	number of obs used in e(LBI)
e(Tcon)	1 if T is constant
e(sigma_u)	panel-level standard deviation
e(sigma_e)	standard deviation of η_{it}
e(r2_w)	R -squared for within model
e(r2_o)	R -squared for overall model
e(r2_b)	R -squared for between model
e(chi2)	χ^2
e(rho_ar)	autocorrelation coefficient
e(rho_fov)	u_i fraction of variance
e(thta_min)	minimum θ
e(thta_5)	θ , 5th percentile
e(thta_50)	θ , 50th percentile
e(thta_95)	θ , 95th percentile
e(thta_max)	maximum θ
e(Tbar)	harmonic mean of group sizes
e(rank)	rank of e(V)

Macros

e(cmd)	xtregar
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(model)	re
e(rhotype)	method of estimating ρ_{ar}
e(dw)	LBI, if requested
e(chi2type)	Wald; type of model χ^2 test
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(V)	VCE for random-effects model

Functions

e(sample)	marks estimation sample
-----------	-------------------------

xtregar, **fe** stores the following in **e()**:

Scalars

e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(mss)	model sum of squares
e(rss)	residual sum of squares
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(d1)	Bhargava et al. Durbin–Watson
e(LBI)	Baltagi–Wu LBI statistic
e(N_LBI)	number of obs used in e(LBI)
e(Tcon)	1 if T is constant
e(corr)	$\text{corr}(u_i, \mathbf{X}b)$
e(sigma_u)	panel-level standard deviation
e(sigma_e)	standard deviation of ϵ_{it}
e(r2_a)	adjusted R -squared
e(r2_w)	R -squared for within model
e(r2_o)	R -squared for overall model
e(r2_b)	R -squared for between model
e(ll)	log likelihood
e(ll_0)	log likelihood, constant-only model
e(rho_ar)	autocorrelation coefficient
e(rho_fov)	u_i fraction of variance
e(F)	F statistic
e(F_f)	F for $u_i=0$
e(df_r)	residual degrees of freedom
e(df_a)	degrees of freedom for absorbed effect
e(df_b)	numerator degrees of freedom for F statistic
e(rmse)	root mean squared error
e(Tbar)	harmonic mean of group sizes
e(rank)	rank of e(V)

Macros

e(cmd)	xtregar
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(wtype)	weight type
e(wexp)	weight expression
e(model)	fe
e(rhotype)	method of estimating ρ_{ar}
e(dw)	LBI, if requested
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

Matrices

e(b)	coefficient vector
e(V)	variance–covariance matrix of the estimators

Functions

e(sample)	marks estimation sample
------------------	-------------------------

Methods and formulas

Consider a linear panel-data model described by (1) and (2). The data can be unbalanced and unequally spaced. Specifically, the dataset contains observations on individual i at times t_{ij} for $j = 1, \dots, n_i$.

Methods and formulas are presented under the following headings:

Estimating ρ
Transforming the data to remove the AR(1) component
The within estimator of the fixed-effects model
The Baltagi–Wu GLS estimator
The test statistics

Estimating ρ

The estimate of ρ is always obtained after removing the group means. Let $\tilde{y}_{it} = y_{it} - \bar{y}_i$, let $\tilde{\mathbf{x}}_{it} = \mathbf{x}_{it} - \bar{\mathbf{x}}_i$, and let $\tilde{\epsilon}_{it} = \epsilon_{it} - \bar{\epsilon}_i$.

Then, except for the `onestep` method, all the estimates of ρ are obtained by running Stata's `prais` on

$$\tilde{y}_{it} = \tilde{\mathbf{x}}_{it}\boldsymbol{\beta} + \tilde{\epsilon}_{it}$$

See [TS] `prais` for the formulas for each of the methods.

When `onestep` is specified, a regression is run on the above equation, and the residuals are obtained. Let $e_{it_{ij}}$ be the residual used to estimate the error $\tilde{\epsilon}_{it_{ij}}$. If $t_{ij} - t_{i,j-1} > 1$, $e_{it_{ij}}$ is set to zero. Given this series of residuals

$$\hat{\rho}_{\text{onestep}} = \frac{n}{m_c} \frac{\sum_{i=1}^N \sum_{t=2}^T e_{it} e_{i,t-1}}{\sum_{i=1}^N \sum_{t=1}^T e_{it}^2}$$

where n is the number of nonzero elements in e and m_c is the number of consecutive pairs of nonzero e_{it} s.

Transforming the data to remove the AR(1) component

After estimating ρ , Baltagi and Wu (1999) derive a transformation of the data that removes the AR(1) component. Their $C_i(\rho)$ can be written as

$$y_{it_{ij}}^* = \begin{cases} (1 - \rho^2)^{1/2} y_{it_{ij}} & \text{if } t_{ij} = 1 \\ (1 - \rho^2)^{1/2} \left\{ y_{i,t_{ij}} \frac{1}{(1 - \rho^{2(t_{ij} - t_{i,j-1})})^{1/2}} - y_{i,t_{i,j-1}} \frac{\rho^{(t_{ij} - t_{i,j-1})}}{(1 - \rho^{2(t_{i,j} - t_{i,j-1})})^{1/2}} \right\} & \text{if } t_{ij} > 1 \end{cases}$$

Using the analogous transform on the independent variables generates transformed data without the AR(1) component. Performing simple OLS on the transformed data leaves behind the residuals μ^* .

The within estimator of the fixed-effects model

To obtain the within estimator, we must transform the data that come from the AR(1) transform. For the within transform to remove the fixed effects, the first observation of each panel must be dropped. Specifically, let

$$\begin{aligned}\check{y}_{it_{ij}} &= y_{it_{ij}}^* - \bar{y}_i^* + \bar{\bar{y}}^* & \forall j > 1 \\ \check{\mathbf{x}}_{it_{ij}} &= \mathbf{x}_{it_{ij}}^* - \bar{\mathbf{x}}_i^* + \bar{\bar{\mathbf{x}}}^* & \forall j > 1 \\ \check{\epsilon}_{it_{ij}} &= \epsilon_{it_{ij}}^* - \bar{\epsilon}_i^* + \bar{\bar{\epsilon}}^* & \forall j > 1\end{aligned}$$

where

$$\begin{aligned}\bar{y}_i^* &= \frac{\sum_{j=2}^{n_i-1} y_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{y}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} y_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1} \\ \bar{\mathbf{x}}_i^* &= \frac{\sum_{j=2}^{n_i-1} \mathbf{x}_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{\mathbf{x}}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} \mathbf{x}_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1} \\ \bar{\epsilon}_i^* &= \frac{\sum_{j=2}^{n_i-1} \epsilon_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{\epsilon}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} \epsilon_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1}\end{aligned}$$

The within estimator of the fixed-effects model is then obtained by running OLS on

$$\check{y}_{it_{ij}} = \alpha + \check{\mathbf{x}}_{it_{ij}} \boldsymbol{\beta} + \check{\epsilon}_{it_{ij}}$$

Reported as R^2 within is the R^2 from the above regression.

Reported as R^2 between is $\left\{ \text{corr}(\bar{\mathbf{x}}_i \hat{\boldsymbol{\beta}}, \bar{y}_i) \right\}^2$.

Reported as R^2 overall is $\left\{ \text{corr}(\mathbf{x}_{it} \hat{\boldsymbol{\beta}}, y_{it}) \right\}^2$.

The Baltagi–Wu GLS estimator

The residuals μ^* can be used to estimate the variance components. Translating the matrix formulas given in [Baltagi and Wu \(1999\)](#) into summations yields the following variance-components estimators:

$$\begin{aligned}\hat{\sigma}_\omega^2 &= \sum_{i=1}^N \frac{(\mu_i^{*'} g_i)^2}{(g_i' g_i)} \\ \hat{\sigma}_\epsilon^2 &= \frac{\left[\sum_{i=1}^N (\mu_i^{*'} \mu_i^*) - \sum_{i=1}^N \left\{ \frac{(\mu_i^{*'} g_i)^2}{(g_i' g_i)} \right\} \right]}{\sum_{i=1}^N (n_i - 1)} \\ \hat{\sigma}_\mu^2 &= \frac{\left[\sum_{i=1}^N \left\{ \frac{(\mu_i^{*'} g_i)^2}{(g_i' g_i)} \right\} - N \hat{\sigma}_\epsilon^2 \right]}{\sum_{i=1}^N (g_i' g_i)}\end{aligned}$$

where

$$g_i = \left[1, \frac{\{1 - \rho^{(t_{i,2} - t_{i,1})}\}}{\{1 - \rho^{2(t_{i,2} - t_{i,1})}\}^{\frac{1}{2}}}, \dots, \frac{\{1 - \rho^{(t_{i,n_i} - t_{i,n_i-1})}\}}{\{1 - \rho^{2(t_{i,n_i} - t_{i,n_i-1})}\}^{\frac{1}{2}}} \right]'$$

and μ_i^* is the $n_i \times 1$ vector of residuals from μ^* that correspond to person i .

Then

$$\hat{\theta}_i = 1 - \left(\frac{\hat{\sigma}_\mu}{\hat{\omega}_i} \right)$$

where

$$\hat{\omega}_i^2 = g_i' g_i \hat{\sigma}_\mu^2 + \hat{\sigma}_\epsilon^2$$

With these estimates in hand, we can transform the data via

$$z_{it_{ij}}^{**} = z_{it_{ij}}^* - \hat{\theta}_i g_{ij} \frac{\sum_{s=1}^{n_i} g_{is} z_{it_{is}}^*}{\sum_{s=1}^{n_i} g_{is}^2}$$

for $z \in \{y, \mathbf{x}\}$.

Running OLS on the transformed data y^{**}, \mathbf{x}^{**} yields the feasible GLS estimator of α and β .

Reported as R^2 between is $\left\{ \text{corr}(\bar{\mathbf{x}}_i \hat{\beta}, \bar{y}_i) \right\}^2$.

Reported as R^2 within is $\left\{ \text{corr}\{(\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \hat{\beta}, y_{it} - \bar{y}_i\} \right\}^2$.

Reported as R^2 overall is $\left\{ \text{corr}(\mathbf{x}_{it} \hat{\beta}, y_{it}) \right\}^2$.

The test statistics

The Baltagi–Wu LBI is the sum of terms

$$d_* = d_1 + d_2 + d_3 + d_4$$

where

$$d_1 = \frac{\sum_{i=1}^N \sum_{j=1}^{n_i} \{\tilde{z}_{it_{i,j-1}} - \tilde{z}_{it_{ij}} I(t_{ij} - t_{i,j-1} = 1)\}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2}$$

$$d_2 = \frac{\sum_{i=1}^N \sum_{j=1}^{n_i-1} \tilde{z}_{it_{i,j-1}}^2 \{1 - I(t_{ij} - t_{i,j-1} = 1)\}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2}$$

$$d_3 = \frac{\sum_{i=1}^N \tilde{z}_{it_{i1}}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2}$$

$$d_4 = \frac{\sum_{i=1}^N \tilde{z}_{it_{in_i}}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2}$$

$I()$ is the indicator function that takes the value of 1 if the condition is true and 0 otherwise. The $\tilde{z}_{it_{i,j-1}}$ are residuals from the within estimator.

Baltagi and Wu (1999) also show that d_1 is the Bhargava et al. Durbin–Watson statistic modified to handle cases of unbalanced panels and unequally spaced data.

Acknowledgment

We thank Badi Baltagi of the Department of Economics at Syracuse University for his helpful comments.

References

- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Baltagi, B. H., and Q. Li. 1991. A transformation that will circumvent the problem of autocorrelation in an error-component model. *Journal of Econometrics* 48: 385–393.
- Baltagi, B. H., and P. X. Wu. 1999. Unequally spaced panel data regressions with AR(1) disturbances. *Econometric Theory* 15: 814–823.
- Bhargava, A., L. Franzini, and W. Narendranathan. 1982. Serial correlation and the fixed effects model. *Review of Economic Studies* 49: 533–549.
- Drukker, D. M. 2003. Testing for serial correlation in linear panel-data models. *Stata Journal* 3: 168–178.
- Hoechle, D. 2007. Robust standard errors for panel regressions with cross-sectional dependence. *Stata Journal* 7: 281–312.
- Hsiao, C. 2003. *Analysis of Panel Data*. 2nd ed. New York: Cambridge University Press.
- Mundlak, Y. 1978. On the pooling of time series and cross section data. *Econometrica* 46: 69–85.
- Sosa-Escudero, W., and A. K. Bera. 2008. Tests for unbalanced error-components models under local misspecification. *Stata Journal* 8: 68–78.

Also see

- [XT] [xtregar](#) [postestimation](#) — Postestimation tools for xtregar
- [XT] [xtset](#) — Declare data to be panel data
- [XT] [xtgee](#) — Fit population-averaged panel-data models by using GEE
- [XT] [xtgls](#) — Fit panel-data models by using GLS
- [XT] [xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [TS] [newey](#) — Regression with Newey–West standard errors
- [TS] [prais](#) — Prais–Winsten and Cochrane–Orcutt regression
- [U] [20 Estimation and postestimation commands](#)

Description

The following postestimation commands are available after `xtregar`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code> ¹	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman’s specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

¹ `estat ic` is not appropriate after `xtregar`, `re`.

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	$\mathbf{x}_{it}\mathbf{b}$, linear prediction; the default
<code>ue</code>	$u_i + e_{it}$, the combined residual
* <code>u</code>	u_i , the fixed- or random-error component
* <code>e</code>	e_{it} , the overall error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction, $\mathbf{x}_{it}\beta$.

ue calculates the prediction of $u_i + e_{it}$.

u calculates the prediction of u_i , the estimated fixed or random effect.

e calculates the prediction of e_{it} .

Also see

[XT] [xtregar](#) — Fixed- and random-effects linear models with an AR(1) disturbance

[U] [20 Estimation and postestimation commands](#)

Syntax

Declare data to be panel

```
xtset panelvar
xtset panelvar timevar [ , tsoptions ]
```

Display how data are currently xtset

```
xtset
```

Clear xt settings

```
xtset, clear
```

In the declare syntax, *panelvar* identifies the panels and the optional *timevar* identifies the times within panels. *tsoptions* concern *timevar*.

<i>tsoptions</i>	Description
unitoptions	specify units of <i>timevar</i>
deltaoption	specify periodicity of <i>timevar</i>
noquery	suppress summary calculations and output

[noquery](#) is not shown in the dialog box.

<i>unitoptions</i>	Description
<i>(default)</i>	<i>timevar</i> 's units to be obtained from <i>timevar</i> 's display format
clocktime	<i>timevar</i> is %tc: 0 = 1jan1960 00:00:00.000, 1 = 1jan1960 00:00:00.001, ...
daily	<i>timevar</i> is %td: 0 = 1jan1960, 1 = 2jan1960, ...
weekly	<i>timevar</i> is %tw: 0 = 1960w1, 1 = 1960w2, ...
monthly	<i>timevar</i> is %tm: 0 = 1960m1, 1 = 1960m2, ...
quarterly	<i>timevar</i> is %tq: 0 = 1960q1, 1 = 1960q2,...
halfyearly	<i>timevar</i> is %th: 0 = 1960h1, 1 = 1960h2,...
yearly	<i>timevar</i> is %ty: 1960 = 1960, 1961 = 1961, ...
generic	<i>timevar</i> is %tg: 0 = ?, 1 = ?, ...
format(%fmt)	specify <i>timevar</i> 's format and then apply default rule

In all cases, negative *timevar* values are allowed.

deltaoption specifies the period between observations in *timevar* units and may be specified as

<i>deltaoption</i>	Example
<code>delta(#)</code>	<code>delta(1)</code> or <code>delta(2)</code>
<code>delta((<i>exp</i>))</code>	<code>delta((7*24))</code>
<code>delta(# <i>units</i>)</code>	<code>delta(7 days)</code> or <code>delta(15 minutes)</code> or <code>delta(7 days 15 minutes)</code>
<code>delta((<i>exp</i>) <i>units</i>)</code>	<code>delta((2+3) weeks)</code>

Allowed units for %tc and %tC *timevars* are

seconds	secs	sec
minutes	mins	min
hours	hour	
days	day	
weeks	week	

and for all other %t *timevars* are

days	day
weeks	week

Menu

Statistics > Longitudinal/panel data > Setup and utilities > Declare dataset to be panel data

Description

`xtset` declares the data in memory to be a panel. You must `xtset` your data before you can use the other `xt` commands. If you `save` your data after `xtset`, the data will be remembered to be a panel and you will not have to `xtset` again.

There are two syntaxes for setting the data:

```
xtset panelvar
xtset panelvar timevar
```

In the first syntax—`xtset panelvar`—the data are set to be a panel and the order of the observations within panel is considered to be irrelevant. For instance, *panelvar* might be country and the observations within might be city.

In the second syntax—`xtset panelvar timevar`—the data are to be a panel and the order of observations within panel are considered ordered by *timevar*. For instance, in data collected from repeated surveying of the same people over various years, *panelvar* might be person and *timevar*, year. When you specify *timevar*, you may then use Stata’s time-series operators such as `L.` and `F.` (lag and lead) in other commands. The operators will be interpreted as lagged and lead values within panel.

`xtset` without arguments—`xtset`—displays how the data are currently `xtset`. If the data are set with a *panelvar* and a *timevar*, `xtset` also sorts the data by *panelvar timevar*. If the data are set with a *panelvar* only, the sort order is not changed.

`xtset, clear` is a rarely used programmer’s command to declare that the data are no longer to be considered a panel.

Options

unitoptions *clocktime*, *daily*, *weekly*, *monthly*, *quarterly*, *halfyearly*, *yearly*, *generic*, and *format(%fmt)* specify the units in which *timevar* is recorded, if *timevar* is specified.

timevar will often simply be a variable that counts 1, 2, ..., and is to be interpreted as first year of survey, second year, ..., or first month of treatment, second month, In these cases, you do not need to specify a *unitoption*.

In other cases, *timevar* will be a year variable or the like such as 2001, 2002, ..., and is to be interpreted as year of survey or the like. In those cases, you do not need to specify a *unitoption*.

In still other, more complicated cases, *timevar* will be a full-blown %t variable; see [D] [datetime](#). If *timevar* already has a %t display format assigned to it, you do not need to specify a *unitoption*; *xtset* will obtain the units from the format. If you have not yet bothered to assign the appropriate %t format to the %t variable, however, you can use the *unitoptions* to tell *xtset* the units. Then *xtset* will set *timevar*'s display format for you. Thus, the *unitoptions* are convenience options; they allow you to skip formatting the time variable. The following all have the same net result:

Alternative 1	Alternative 2	Alternative 3
<code>format t %td</code>	<i>(t not formatted)</i>	<i>(t not formatted)</i>
<code>xtset pid t</code>	<code>xtset pid t, daily</code>	<code>xtset pid t, format(%td)</code>

Understand that *timevar* is not required to be a %t variable; it can be any variable of your own concocting so long as it takes on integer values. When you *xtset* a time variable that is not %t, the display format does not change unless you specify the *unitoption* *generic* or use the *format()* option.

delta() specifies the periodicity of *timevar* and is commonly used when *timevar* is %tc. *delta()* is only sometimes used with the other %t formats or with generic time variables.

If *delta()* is not specified, *delta(1)* is assumed. This means that at *timevar* = 5, the previous time is *timevar* = 5 - 1 = 4 and the next time would be *timevar* = 5 + 1 = 6. Lag and lead operators, for instance, would work this way. This would be assumed regardless of the units of *timevar*.

If you specified *delta(2)*, then at *timevar* = 5, the previous time would be *timevar* = 5 - 2 = 3 and the next time would be *timevar* = 5 + 2 = 7. Lag and lead operators would work this way. In the observation with *timevar* = 5, *L.income* would be the value of *income* in the observation for which *timevar* = 3 and *F.income* would be the value of *income* in the observation for which *timevar* = 7. If you then add an observation with *timevar* = 4, the operators will still work appropriately; that is, at *timevar* = 5, *L.income* will still have the value of *income* at *timevar* = 3.

There are two aspects of *timevar*: its units and its periodicity. The *unitoptions* set the units. *delta()* sets the periodicity. You are not required to specify one to specify the other. You might have a generic *timevar* but it counts in 12: 0, 12, 24, You would skip specifying *unitoptions* but would specify *delta(12)*.

We mentioned that *delta()* is commonly used with %tc *timevars* because Stata's %tc variables have units of milliseconds. If *delta()* is not specified and in some model you refer to *L.bp*, you will be referring to the value of *bp* 1 ms ago. Few people have data with periodicity of a millisecond. Perhaps your data are hourly. You could specify *delta(3600000)*. Or you could specify *delta((60*60*1000))*, because *delta()* will allow expressions if you include an extra pair of parentheses. Or you could specify *delta(1 hour)*. They all mean the same thing: *timevar* has periodicity of 3,600,000 ms. In an observation for which *timevar* = 1,489,572,000,000 (corresponding to 15mar2007 10:00:00), *L.bp* would be the observation for which *timevar* = 1,489,572,000,000 - 3,600,000 = 1,489,568,400,000 (corresponding to 15mar2007 9:00:00).

When you `xtset` the data and specify `delta()`, `xtset` verifies that all the observations follow the specified periodicity. For instance, if you specified `delta(2)`, then *timevar* could contain any subset of $\{\dots, -4, -2, 0, 2, 4, \dots\}$ or it could contain any subset of $\{\dots, -3, -1, 1, 3, \dots\}$. If *timevar* contained a mix of values, `xtset` would issue an error message. The check is made on each panel independently, so one panel might contain *timevar* values from one set and the next, another, and that would be fine.

`clear`—used in `xtset`, `clear`—makes Stata forget that the data ever were `xtset`. This is a rarely used programmer’s option.

The following option is available with `xtset` but is not shown in the dialog box:

`noquery` prevents `xtset` from performing most of its summary calculations and suppresses output.

With this option, only the following results are posted:

<code>r(tdelta)</code>	<code>r(tsfmt)</code>
<code>r(panelvar)</code>	<code>r(unit)</code>
<code>r(timevar)</code>	<code>r(unit1)</code>

Remarks and examples

`xtset` declares the dataset in memory to be panel data. You need to do this before you can use the other `xt` commands. The storage types of both *panelvar* and *timevar* must be numeric, and both variables must contain integers only.

□ Technical note

In previous versions of Stata there was no `xtset` command. The other `xt` commands instead had the `i(panelvar)` and `t(timevar)` options. Older commands still have those options, but they are no longer documented and, if you specify them, they just perform the `xtset` for you. Thus, `do-files` that you previously wrote will continue to work. Modern usage, however, is to `xtset` the data first. □

□ Technical note

`xtset` is related to the `tsset` command, which declares data to be time series. One of the syntaxes of `tsset` is `tsset panelvar timevar`, which is identical to one of `xtset`’s syntaxes, namely, `xtset panelvar timevar`. Here they are in fact the same command, meaning that `xtsetting` your data is sufficient to allow you to use the `ts` commands and `tssetting` your data is sufficient to allow you to use the `xt` commands. You do not need to set both, but it will not matter if you do.

`xtset` and `tsset` are different, however, when you set just a *panelvar*—you type `xtset panelvar`—or when you set just a *timevar*—you type `tsset timevar`. □

▷ Example 1: Panel data without a time variable

Many panel datasets contain a variable identifying panels but do not contain a time variable. For example, you may have a dataset where each panel is a family, and the observations within panel are family members, or you may have a dataset in which each person made a decision multiple times but the ordering of those decisions is unimportant and perhaps unknown. In this latter case, if the time

of the decision were known, we would advise you to `xtset` it. The other `xt` statistical commands do not do something different because *timevar* has been set—they will ignore *timevar* if *timevar* is irrelevant to the statistical method that you are using. You should always set everything that is true about the data.

In any case, let’s consider the case where there is no *timevar*. We have data on U.S. states and cities within states:

```
. list state city in 1/10, sepby(state)
```

	state	city
1.	Alabama	Birmingham
2.	Alabama	Mobile
3.	Alabama	Montgomery
4.	Alabama	Huntsville
5.	Alaska	Anchorage
6.	Alaska	Fairbanks
7.	Arizona	Phoenix
8.	Arizona	Tucson
9.	Arkansas	Fayetteville
10.	Arkansas	Fort Smith

Here we do not type `xtset state city` because *city* is not a time variable. Instead, we type `xtset state`:

```
. xtset state
varlist:  state:  string variable not allowed
r(109);
```

You cannot `xtset` a string variable. We must make a numeric variable from our string variable and `xtset` that. One alternative is

```
. egen statenum = group(state)
. list state statenum in 1/10, sepby(state)
```

	state	statenum
1.	Alabama	1
2.	Alabama	1
3.	Alabama	1
4.	Alabama	1
5.	Alaska	2
6.	Alaska	2
7.	Arizona	3
8.	Arizona	3
9.	Arkansas	4
10.	Arkansas	4

```
. xtset statenum
panel variable:  statenum (unbalanced)
```


Perhaps a better alternative is

```
. encode state, gen(st)
. list state st in 1/10, sepby(state)
```

	state	st
1.	Alabama	Alabama
2.	Alabama	Alabama
3.	Alabama	Alabama
4.	Alabama	Alabama
5.	Alaska	Alaska
6.	Alaska	Alaska
7.	Arizona	Arizona
8.	Arizona	Arizona
9.	Arkansas	Arkansas
10.	Arkansas	Arkansas

`encode` (see [D] [encode](#)) produces a numeric variable with a value label, so when we list the result, new variable `st` looks just like our original. It is, however, numeric:

```
. list state st in 1/10, nlabel sepby(state)
```

	state	st
1.	Alabama	1
2.	Alabama	1
3.	Alabama	1
4.	Alabama	1
5.	Alaska	2
6.	Alaska	2
7.	Arizona	3
8.	Arizona	3
9.	Arkansas	4
10.	Arkansas	4

We can `xtset` new variable `st`:

```
. xtset st
      panel variable:  st (unbalanced)
```



➤ Example 2: Panel data with a time variable

Some panel datasets do contain a time variable. Dataset `abdata.dta` contains labor demand data from a panel of firms in the United Kingdom. Here are wage data for the first two firms in the dataset:


```
. use http://www.stata-press.com/data/r13/abdata, clear
. list id year wage if id==1 | id==2, sepby(id)
```

	id	year	wage
1.	1	1977	13.1516
2.	1	1978	12.3018
3.	1	1979	12.8395
4.	1	1980	13.8039
5.	1	1981	14.2897
6.	1	1982	14.8681
7.	1	1983	13.7784
8.	2	1977	14.7909
9.	2	1978	14.1036
10.	2	1979	14.9534
11.	2	1980	15.491
12.	2	1981	16.1969
13.	2	1982	16.1314
14.	2	1983	16.3051

To declare this dataset as a panel dataset, you type

```
. xtset id year, yearly
      panel variable:  id (unbalanced)
      time variable:  year, 1976 to 1984
                  delta: 1 year
```

The output from `list` shows that the last observations for these two firms are for 1983, but `xtset` shows that for some firms data are available for 1984 as well. If one or more panels contain data for nonconsecutive periods, `xtset` will report that gaps exist in the time variable. For example, if we did not have data for firm 1 for 1980 but did have data for 1979 and 1981, `xtset` would indicate that our data have a gap.

For yearly data, we could omit the `yearly` option and just type `xtset id year` because years are stored and listed just like regular integers.

Having declared our data to be a panel dataset, we can use time-series operators to obtain lags:

```
. list id year wage L.wage if id==1 | id==2, sepby(id)
```

	id	year	wage	L.wage
1.	1	1977	13.1516	.
2.	1	1978	12.3018	13.1516
(output omitted)				
6.	1	1982	14.8681	14.2897
7.	1	1983	13.7784	14.8681
8.	2	1977	14.7909	.
9.	2	1978	14.1036	14.7909
(output omitted)				
13.	2	1982	16.1314	16.1969
14.	2	1983	16.3051	16.1314

`L.wage` is missing for 1977 in both panels because we have no wage data for 1976. In observation 8, the lag operator did not incorrectly reach back into the previous panel.

□ Technical note

The terms *balanced* and *unbalanced* are often used to describe whether a panel dataset is missing some observations. If a dataset does not contain a time variable, then panels are considered *balanced* if each panel contains the same number of observations; otherwise, the panels are *unbalanced*.

When the dataset contains a time variable, panels are said to be *strongly balanced* if each panel contains the same time points, *weakly balanced* if each panel contains the same number of observations but not the same time points, and *unbalanced* otherwise.

□

▷ Example 3: Applying time-series formats to the time variable

If our data are observed more than once per year, applying time-series formats to the time variable can improve readability.

We have a dataset consisting of individuals who joined a gym’s weight-loss program that began in January 2005 and ended in December 2005. Each participant’s weight was recorded once per month. Some participants did not show up for all the monthly weigh-ins, so we do not have all 12 months’ records for each person. The first two people’s data are

```
. use http://www.stata-press.com/data/r13/gymdata
. list id month wt if id==1 | id==2, sepby(id)
```

	id	month	wt
1.	1	1	145
2.	1	2	144
	(output omitted)		
11.	1	11	124
12.	1	12	120
	(output omitted)		
13.	2	1	144
14.	2	2	143
	(output omitted)		
23.	2	11	122
24.	2	12	118

To set these data, we can type

```
. xtset id month
      panel variable:  id (unbalanced)
      time variable:  month, 1 to 12, but with gaps
                  delta:  1 unit
```

The note “but with gaps” above is no cause for concern. It merely warns us that, within some panels, some time values are missing. We already knew that about our data—some participants did not show up for the monthly weigh-ins.

The rest of this example concerns making output more readable. Month numbers such as 1, 2, . . . , 12 are perfectly readable here. In another dataset, where month numbers went to, say 127, they would not be so readable. In such cases, we can make a more readable date—2005m1, 2005m2, . . .—by using Stata’s %t variables. For a discussion, see [\[D\] datetime](#). We will go quickly here. One of the %t formats is %tm—monthly—and it says that 1 means 1960m1. Thus, we need to recode our month variable so that, rather than taking on values from 1 to 12, it takes on values from 540 to 551. Then we can put a %tm format on that variable. Working out 540–551 is subject to mistakes. Stata function tm(2005m1) tells us the %tm month corresponding to January of 2005, so we can type


```
. generate month2 = month + tm(2005m1) - 1
. format month2 %tm
```

New variable `month2` will work just as well as the original `month` in an `xtset`, and even a little better, because output will be a little more readable:

```
. xtset id month2
      panel variable:  id (unbalanced)
      time variable:  month2, 2005m1 to 2005m12, but with gaps
                    delta: 1 month
```

By the way, we could have omitted typing `format month2 %tm` and then, rather than typing `xtset id month2`, we would have typed `xtset id month2, monthly`. The `monthly` option specifies that the time variable is `%tm`. When we did not specify the option, `xtset` determined that it was monthly from the display format we had set.



► **Example 4: Clock times**

We have data from a large hotel in Las Vegas that changes the reservation prices for its room reservations hourly. A piece of the data looks like

```
. list in 1/5
```

	roomtype	time	price
1.	1	02.13.2007 08:00	140
2.	1	02.13.2007 09:00	155
3.	1	02.13.2007 10:00	160
4.	1	02.13.2007 11:00	155
5.	1	02.13.2007 12:00	160

The panel variable is `roomtype` and, although you cannot see it from the output above, it takes on 1, 2, ..., 20. Variable `time` is a string variable. The first step in making this dataset `xt` is to translate the string to a numeric variable:

```
. generate double t = clock(time, "MDY hm")
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1.487e+12
2.	1	02.13.2007 09:00	155	1.487e+12
3.	1	02.13.2007 10:00	160	1.487e+12
4.	1	02.13.2007 11:00	155	1.487e+12
5.	1	02.13.2007 12:00	160	1.487e+12

See [\[D\] datetime translation](#) for an explanation of what is going on here. `clock()` is the function that converts strings to datetime (`%tc`) values. We typed `clock(time, "MDY hm")` to convert string variable `time`, and we told `clock()` that the values in `time` were in the order month, day, year, hour, and minute. We stored new variable `t` as a `double` because time values are large and that is required to prevent rounding. Even so, the resulting values `1.487e+12` look rounded, but that is only because of the default display format for new variables. We can see the values better if we change the format:


```
. format t %20.0gc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1,486,972,800,000
2.	1	02.13.2007 09:00	155	1,486,976,400,000
3.	1	02.13.2007 10:00	160	1,486,980,000,000
4.	1	02.13.2007 11:00	155	1,486,983,600,000
5.	1	02.13.2007 12:00	160	1,486,987,200,000

Even better, however, would be to change the format to %tc—Stata’s clock-time format:

```
. format t %tc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	13feb2007 08:00:00
2.	1	02.13.2007 09:00	155	13feb2007 09:00:00
3.	1	02.13.2007 10:00	160	13feb2007 10:00:00
4.	1	02.13.2007 11:00	155	13feb2007 11:00:00
5.	1	02.13.2007 12:00	160	13feb2007 12:00:00

We could now drop variable `time`. New variable `t` contains the same information as `time` and it is better because it is a Stata time variable, the most important property of which being that it is numeric rather than string. We can `xtset` it. Here, however, we also need to specify the periodicity with `xtset`’s `delta()` option. Stata’s time variables are numeric, but they record milliseconds since 01jan1960 00:00:00. By default, `xtset` uses `delta(1)`, and that means the time-series operators would not work as we want them to work. For instance, `L.price` would look back only 1 ms (and find nothing). We want `L.price` to look back 1 hour (3,600,000 ms):

```
. xtset roomtype t, delta(1 hour)
      panel variable:  roomtype (strongly balanced)
      time variable:  t,
                      13feb2007 08:00:00 to 31mar2007 18:00:00,
                      but with gaps
      delta: 1 hour
. list t price l.price in 1/5
```

	t	price	L.price
1.	13feb2007 08:00:00	140	.
2.	13feb2007 09:00:00	155	140
3.	13feb2007 10:00:00	160	155
4.	13feb2007 11:00:00	155	160
5.	13feb2007 12:00:00	160	155

► Example 5: Clock times must be double

In the previous example, it was of vital importance that when we generated the %tc variable `t`, we generated it as a double. Let's see what would have happened had we forgotten and just typed `generate t = clock(time, "MDY hm")`. Let's go back and start with the same original data:

```
. list in 1/5
```

	roomtype	time	price
1.	1	02.13.2007 08:00	140
2.	1	02.13.2007 09:00	155
3.	1	02.13.2007 10:00	160
4.	1	02.13.2007 11:00	155
5.	1	02.13.2007 12:00	160

Remember, variable `time` is a string variable, and we need to translate it to numeric. So we translate, but this time we forget to make the new variable a double:

```
. generate t = clock(time, "MDY hm")
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1.49e+12
2.	1	02.13.2007 09:00	155	1.49e+12
3.	1	02.13.2007 10:00	160	1.49e+12
4.	1	02.13.2007 11:00	155	1.49e+12
5.	1	02.13.2007 12:00	160	1.49e+12

We see the first difference—`t` now lists as 1.49e+12 rather than 1.487e+12 as it did previously—but this is nothing that would catch our attention. We would not even know that the value is different. Let's continue.

We next put a %20.0gc format on `t` to better see the numerical values. In fact, that is not something we would usually do in an analysis. We did that in the example to emphasize to you that the `t` values were really big numbers. We will repeat the exercise just to be complete, but in real analysis, we would not bother.

```
. format t %20.0gc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1,486,972,780,544
2.	1	02.13.2007 09:00	155	1,486,976,450,560
3.	1	02.13.2007 10:00	160	1,486,979,989,504
4.	1	02.13.2007 11:00	155	1,486,983,659,520
5.	1	02.13.2007 12:00	160	1,486,987,198,464

Okay, we see big numbers in `t`. Let's continue.

Next we put a %tc format on `t`, and that is something we would usually do, and you should always do. You should also list a bit of the data, as we did:


```
. format t %tc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	13feb2007 07:59:40
2.	1	02.13.2007 09:00	155	13feb2007 09:00:50
3.	1	02.13.2007 10:00	160	13feb2007 09:59:49
4.	1	02.13.2007 11:00	155	13feb2007 11:00:59
5.	1	02.13.2007 12:00	160	13feb2007 11:59:58

By now, you should see a problem: the translated datetime values are off by a second or two. That was caused by rounding. Dates and times should be the same, not approximately the same, and when you see a difference like this, you should say to yourself, “The translation is off a little. Why is that?” and then you should think, “Of course, rounding. I bet that I did not create `t` as a double.”

Let’s assume, however, that you do not do this. You instead plow ahead:

```
. xtset roomtype t, delta(1 hour)
time values with periodicity less than delta() found
r(451);
```

And that is what will happen when you forget to create `t` as a double. The rounding will cause uneven periodicity, and `xtset` will complain.

By the way, it is important only that clock times (`%tc` and `%tC` variables) be stored as doubles. The other date values `%td`, `%tw`, `%tm`, `%tq`, `%th`, and `%ty` are small enough that they can safely be stored as floats, although forgetting and storing them as doubles does no harm.

◀

□ Technical note

Stata provides two clock-time formats, `%tc` and `%tC`. `%tC` provides a clock with leap seconds. Leap seconds are occasionally inserted to account for randomness of the earth’s rotation, which gradually slows. Unlike the extra day inserted in leap years, the timing of when leap seconds will be inserted cannot be foretold. The authorities in charge of such matters announce a leap second approximately 6 months before insertion. Leap seconds are inserted at the end of the day, and the leap second is called 23:59:60 (that is, 11:59:60 pm), which is then followed by the usual 00:00:00 (12:00:00 am). Most nonastronomers find these leap seconds vexing. The added seconds cause problems because of their lack of predictability—knowing how many seconds there will be between 01jan2012 and 01jan2013 is not possible—and because there are not necessarily 24 hours in a day. If you use a leap second–adjusted clock, most days have 24 hours, but a few have 24 hours and 1 second. You must look at a table to find out.

From a time-series analysis point of view, the nonconstant day causes the most problems. Let’s say that you have data on blood pressure for a set of patients, taken hourly at 1:00, 2:00, . . . , and that you have `xtset` your data with `delta(1 hour)`. On most days, `L24.bp` would be blood pressure at the same time yesterday. If the previous day had a leap second, however, and your data were recorded using a leap second–adjusted clock, there would be no observation `L24.bp` because 86,400 seconds before the current reading does not correspond to an on-the-hour time; 86,401 seconds before the current reading corresponds to yesterday’s time. Thus, whenever possible, using Stata’s `%tc` encoding rather than `%tC` is better.

When times are recorded by computers using leap second–adjusted clocks, however, avoiding `%tC` is not possible. For performing most time-series analysis, the recommended procedure is to map the

%tC values to %tc and then **xtset** those. You must ask yourself whether the process you are studying is based on the clock—the nurse does something at 2 o’clock every day—or the true passage of time—the emitter spits out an electron every 86,400,000 ms.

When dealing with computer-recorded times, first find out whether the computer (and its time-recording software) use a leap second–adjusted clock. If it does, translate that to a %tC value. Then use function **cofC()** to convert to a %tc value and **xtset** that. If variable **T** contains the %tC value,

```
. generate double t = cofC(T)
. format t %tc
. xtset panelvar t, delta(...)
```

Function **cofC()** moves leap seconds forward: 23:59:60 becomes 00:00:00 of the next day.



Stored results

xtset stores the following in **r()**:

Scalars

r(imin)	minimum panel ID
r(imax)	maximum panel ID
r(tmin)	minimum time
r(tmax)	maximum time
r(tdelta)	delta

Macros

r(panelvar)	name of panel variable
r(timevar)	name of time variable
r(tdeltas)	formatted delta
r(tmins)	formatted minimum time
r(tmaxs)	formatted maximum time
r(tsfmt)	%fmt of time variable
r(unit)	units of time variable: Clock, clock, daily, weekly, monthly, quarterly, halfyearly, yearly, or generic
r(unit1)	units of time variable: C, c, d, w, m, q, h, y, or ""
r(balanced)	unbalanced, weakly balanced, or strongly balanced; a set of panels are strongly balanced if they all have the same time values, otherwise balanced if same number of time values, otherwise unbalanced

Also see

[XT] **xtdescribe** — Describe pattern of xt data

[XT] **xtsum** — Summarize xt data

[TS] **tsset** — Declare data to be time-series data

[TS] **tsfill** — Fill in gaps in time variable

	Syntax	Menu	Description	Remarks and examples
	Stored results	Also see		

Syntax

```
xtsum [varlist] [if]
```

A panel variable must be specified; use `xtset`; see [XT] `xtset`.
`varlist` may contain time-series operators; see [U] 11.4.4 Time-series varlists.
`by` is allowed; see [D] `by`.

Menu

Statistics > Longitudinal/panel data > Setup and utilities > Summarize xt data

Description

`xtsum`, a generalization of `summarize` (see [R] `summarize`), reports means and standard deviations for panel data; it differs from `summarize` in that it decomposes the standard deviation into between and within components.

Remarks and examples

If you have not read [XT] `xt`, please do so.

`xtsum` provides an alternative to `summarize`. For instance, in the `nlswork` dataset described in [XT] `xt`, `hours` contains the usual hours worked:

```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. summarize hours
```

Variable	Obs	Mean	Std. Dev.	Min	Max
hours	28467	36.55956	9.869623	1	168

```
. xtsum hours
```

Variable		Mean	Std. Dev.	Min	Max	Observations
hours	overall	36.55956	9.869623	1	168	N = 28467
	between		7.846585	1	83.5	n = 4710
	within		7.520712	-2.154726	130.0596	T-bar = 6.04395

`xtsum` provides the same information as `summarize` and more. It decomposes the variable x_{it} into a between (\bar{x}_i) and within ($x_{it} - \bar{x}_i + \bar{\bar{x}}$, the global mean $\bar{\bar{x}}$ being added back in make results comparable). The overall and within are calculated over 28,467 person-years of data. The between is calculated over 4,710 persons, and the average number of years a person was observed in the `hours` data is 6.

`xtsum` also reports minimums and maximums. Hours worked last week varied between 1 and (unbelievably) 168. Average hours worked last week for each woman varied between 1 and 83.5. “Hours worked within” varied between -2.15 and 130.1 , which is not to say that any woman actually worked negative hours. The within number refers to the deviation from each individual’s average, and naturally, some of those deviations must be negative. Then the negative value is not disturbing but the positive value is. Did some woman really deviate from her average by $+130.1$ hours? No. In our definition of within, we add back in the global average of 36.6 hours. Some woman did deviate from her average by $130.1 - 36.6 = 93.5$ hours, which is still large.

The reported standard deviations tell us something that may surprise you. They say that the variation in hours worked last week across women is nearly equal to that observed within a woman over time. That is, if you were to draw two women randomly from our data, the difference in hours worked is expected to be nearly equal to the difference for the same woman in two randomly selected years.

If a variable does not vary over time, its within standard deviation will be zero:

```
. xtsum birth_yr
```

Variable	Mean	Std. Dev.	Min	Max	Observations
birth_yr overall	48.08509	3.012837	41	54	N = 28534
between		3.051795	41	54	n = 4711
within		0	48.08509	48.08509	T-bar = 6.05689

Stored results

`xtsum` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(n)</code>	number of panels
<code>r(Tbar)</code>	average number of years under observation
<code>r(mean)</code>	mean
<code>r(sd)</code>	overall standard deviation
<code>r(min)</code>	overall minimum
<code>r(max)</code>	overall maximum
<code>r(sd_b)</code>	between standard deviation
<code>r(min_b)</code>	between minimum
<code>r(max_b)</code>	between maximum
<code>r(sd_w)</code>	within standard deviation
<code>r(min_w)</code>	within minimum
<code>r(max_w)</code>	within maximum

Also see

- [XT] `xtdescribe` — Describe pattern of xt data
- [XT] `xttab` — Tabulate xt data

Syntax	Menu	Description	Option
Remarks and examples	Stored results	Also see	

Syntax

```
xttab varname [if]  
  
xttrans varname [if] [, freq]
```

A panel variable must be specified; use `xtset`; see [\[XT\]](#) `xtset`.
`by` is allowed with `xttab` and `xttrans`; see [\[D\]](#) `by`.

Menu

xttab

Statistics > Longitudinal/panel data > Setup and utilities > Tabulate xt data

xttrans

Statistics > Longitudinal/panel data > Setup and utilities > Report transition probabilities

Description

`xttab`, a generalization of `tabulate` (see [\[R\]](#) [tabulate oneway](#)), performs one-way tabulations and decomposes counts into between and within components in panel data.

`xttrans`, another generalization of `tabulate` (see [\[R\]](#) [tabulate oneway](#)), reports transition probabilities (the change in one categorical variable over time).

Option

Main

`freq`, allowed with `xttrans` only, specifies that frequencies as well as transition probabilities be displayed.

Remarks and examples

If you have not read [\[XT\]](#) `xt`, please do so.

➤ Example 1: xttab

Using the `nlswork` dataset described in [\[XT\]](#) `xt`, variable `msp` is 1 if a woman is married and her spouse resides with her, and 0 otherwise:


```
. use http://www.stata-press.com/data/r13/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. xxtab msp
```

msp	Overall		Between		Within
	Freq.	Percent	Freq.	Percent	Percent
0	11324	39.71	3113	66.08	62.69
1	17194	60.29	3643	77.33	75.75
Total	28518	100.00	6756	143.41	69.73

(n = 4711)

The overall part of the table summarizes results in terms of person-years. We have 11,324 person-years of data in which msp is 0 and 17,194 in which it is 1—in 60.3% of our data, the woman is married with her spouse present. Between repeats the breakdown, but this time in terms of women rather than person-years; 3,113 of our women ever had msp 0 and 3,643 ever had msp 1, for a grand total of 6,756 ever having either. We have in our data, however, only 4,711 women. This means that there are women who sometimes have msp 0 and at other times have msp 1.

The within percent tells us the fraction of the time a woman has the specified value of msp. If we take the first line, conditional on a woman ever having msp 0, 62.7% of her observations have msp 0. Similarly, conditional on a woman ever having msp 1, 75.8% of her observations have msp 1. These two numbers are a measure of the stability of the msp values, and, in fact, msp 1 is more stable among these younger women than msp 0, meaning that they tend to marry more than they divorce. The total within of 69.75% is the normalized between weighted average of the within percents, that is, $(3113 \times 62.69 + 3643 \times 75.75)/6756$. It is a measure of the overall stability of the msp variable.

A time-invariant variable will have a tabulation with within percents of 100:

```
. xxtab race
```

race	Overall		Between		Within
	Freq.	Percent	Freq.	Percent	Percent
white	20180	70.72	3329	70.66	100.00
black	8051	28.22	1325	28.13	100.00
other	303	1.06	57	1.21	100.00
Total	28534	100.00	4711	100.00	100.00

(n = 4711)

➤ Example 2: xtrans

xtrans shows the transition probabilities. In cross-sectional time-series data, we can estimate the probability that $x_{i,t+1} = v_2$ given that $x_{it} = v_1$ by counting transitions. For instance

```
. xtrans msp
```

1 if married, spouse present	1 if married, spouse present		Total
	0	1	
0	80.49	19.51	100.00
1	7.96	92.04	100.00
Total	37.11	62.89	100.00

The rows reflect the initial values, and the columns reflect the final values. Each year, some 80% of the msp 0 persons in the data remained msp 0 in the next year; the remaining 20% became msp 1. Although msp 0 had a 20% chance of becoming msp 1 in each year, the msp 1 had only an 8% chance of becoming (or returning to) msp 0. The freq option displays the frequencies that go into the calculation:

```
. xttrans msp, freq
```

1 if married, spouse present	1 if married, spouse present		Total
	0	1	
0	7,697 80.49	1,866 19.51	9,563 100.00
1	1,133 7.96	13,100 92.04	14,233 100.00
Total	8,830 37.11	14,966 62.89	23,796 100.00



❑ Technical note

The transition probabilities reported by xttrans are not necessarily the transition probabilities in a Markov sense. xttrans counts transitions from each observation to the next once the observations have been put in *t* order within *i*. It does not normalize for missing periods. xttrans does pay attention to missing values of the variable being tabulated, however, and does not count transitions from nonmissing to missing or from missing to nonmissing. Thus if the data are fully rectangularized, xttrans produces (inefficient) estimates of the Markov transition matrix. fillin will rectangularize datasets; see [D] fillin. Thus the Markov transition matrix could be estimated by typing

```
. fillin idcode year
. xttrans msp
(output omitted)
```



Stored results

xttab stores the following in r():

Scalars	
r(n)	number of panels
Matrices	
r(results)	results matrix

Also see

- [XT] [xtdescribe](#) — Describe pattern of xt data
- [XT] [xtsum](#) — Summarize xt data

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	References
Also see			

Syntax

```
xttobit depvar [indepvars] [if] [in] [weight] [, options]
```

options	Description
Model	
<u>noconstant</u>	suppress constant term
<u>ll</u> (varname #)	left-censoring variable/limit
<u>ul</u> (varname #)	right-censoring variable/limit
<u>offset</u> (varname)	include varname in model with coefficient constrained to 1
<u>constraints</u> (constraints)	apply specified linear constraints
<u>collinear</u>	keep collinear variables
SE	
<u>vce</u> (vcetype)	vcetype may be oim, <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>tobit</u>	perform likelihood-ratio test comparing against pooled tobit model
<u>noskip</u>	perform overall model test as a likelihood-ratio test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> (intmethod)	integration method; intmethod may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is intpoints(12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; use xtset; see [XT] [xtset](#).
indepvars may contain factor variables; see [U] [11.4.3 Factor variables](#).
depvar and indepvars may contain time-series operators; see [U] [11.4.4 Time-series varlists](#).
by, fp, and statsby are allowed; see [U] [11.1.10 Prefix commands](#).
iweights are allowed; see [U] [11.1.6 weight](#). Weights must be constant within panel.
coeflegend does not appear in the dialog box.
See [U] [20 Estimation and postestimation commands](#) for more capabilities of estimation commands.

Menu

Statistics > Longitudinal/panel data > Censored outcomes > Tobit regression (RE)

Description

`xttobit` fits random-effects tobit models. There is no command for a parametric conditional fixed-effects model, as there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood. [Honoré \(1992\)](#) has developed a semiparametric estimator for fixed-effect tobit models. Unconditional fixed-effects tobit models may be fit with the `tobit` command with indicator variables for the panels; the indicators can be created with the factor-variable syntax described in [\[U\] 11.4.3 Factor variables](#). However, unconditional fixed-effects estimates are biased.

Options

Model

`noconstant`; see [\[R\] estimation options](#).

`ll(varname|#)` and `ul(varname|#)` indicate the censoring points. You may specify one or both. `ll()` indicates the lower limit for left-censoring. Observations with `depvar ≤ ll()` are left-censored, observations with `depvar ≥ ul()` are right-censored, and remaining observations are not censored.

`offset(varname)`, `constraints(constraints)`, `collinear`; see [\[R\] estimation options](#).

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce_options](#).

Reporting

`level(#)`; see [\[R\] estimation options](#).

`tobit` specifies that a likelihood-ratio test comparing the random-effects model with the pooled (tobit) model be included in the output.

`noskip`; see [\[R\] estimation options](#).

`nocnsreport`; see [\[R\] estimation options](#).

`display_options`: `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] estimation options](#).

Integration

`intmethod(intmethod)`, `intpoints(#)`; see [\[R\] estimation options](#).

Maximization

`maximize_options`: `difficult`, `technique(algorithm-spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrntolerance`, and `from(init-specs)`; see [\[R\] maximize](#). These options are seldom used.

The following option is available with `xttobit` but is not shown in the dialog box:

`coeflegend`; see [\[R\] estimation options](#).

The output includes the overall and panel-level variance components (labeled `sigma_e` and `sigma_u`, respectively) together with ρ (labeled `rho`)

$$\rho = \frac{\sigma_u^2}{\sigma_e^2 + \sigma_u^2}$$

which is the percent contribution to the total variance of the panel-level variance component.

When `rho` is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (tobit) with the panel estimator.

◀

□ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] [quadchk](#) for details and [XT] [xtprobit](#) for an [example](#).

Because the `xttobit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.

□

Stored results

`xttobit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_unc)</code>	number of uncensored observations
<code>e(N_l1c)</code>	number of left-censored observations
<code>e(N_rc)</code>	number of right-censored observations
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(chi2)</code>	χ^2
<code>e(chi2_c)</code>	χ^2 for comparison test
<code>e(rho)</code>	ρ
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of ϵ_{it}
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	significance
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>xttobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	names of dependent variables
<code>e(ivar)</code>	variable denoting groups
<code>e(llopt)</code>	contents of <code>ll()</code> , if specified
<code>e(ulopt)</code>	contents of <code>ul()</code> , if specified
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset1)</code>	offset
<code>e(chi2type)</code>	Wald or LR; type of model χ^2 test
<code>e(chi2_ct)</code>	Wald or LR; type of model χ^2 test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vctype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

Matrices	
<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance–covariance matrix of the estimator
Functions	
<code>e(sample)</code>	marks estimation sample

Methods and formulas

Assuming a normal distribution, $N(0, \sigma_\nu^2)$, for the random effects ν_i , we have the joint (unconditional of ν_i) density of the observed data from the i th panel

$$f(y_{i1}^o, \dots, y_{in_i}^o | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y_{it}^o, \Delta_{it}) = \begin{cases} (\sqrt{2\pi}\sigma_\epsilon)^{-1} e^{-(y_{it}^o - \Delta_{it})^2/(2\sigma_\epsilon^2)} & \text{if } y_{it}^o \in C \\ \Phi\left(\frac{y_{it}^o - \Delta_{it}}{\sigma_\epsilon}\right) & \text{if } y_{it}^o \in L \\ 1 - \Phi\left(\frac{y_{it}^o - \Delta_{it}}{\sigma_\epsilon}\right) & \text{if } y_{it}^o \in R \end{cases}$$

where C is the set of noncensored observations, L is the set of left-censored observations, R is the set of right-censored observations, and $\Phi(\cdot)$ is the cumulative normal distribution.

The panel level likelihood l_i is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}^o, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with M -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the w_m^* denote the quadrature weights and the a_m^* denote the quadrature abscissas. The log likelihood, L , is the sum of the logs of the panel level likelihoods l_i .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where $\hat{\sigma}_i$ and $\hat{\mu}_i$ are the adaptive parameters for panel i . Therefore, with the definition of $g(y_{it}^o, x_{it}, \nu_i)$, the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[\sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)^2 / 2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \prod_{t=1}^{n_i} F(y_{it}^o, x_{it}, \beta + \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i) \right]$$

where w_i is the user-specified weight for panel i ; if no weights are specified, $w_i = 1$.

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for $\hat{\mu}_i$ and $\hat{\sigma}_i$ by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with $\hat{\sigma}_{i,0} = 1$ and $\hat{\mu}_{i,0} = 0$, and the posterior means and variances are updated in the k th iteration. That is, at the k th iteration of the optimization for l_i we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2}\hat{\sigma}_{i,k-1} w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \sqrt{2}\hat{\sigma}_{i,k-1} a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2}\hat{\sigma}_{i,k-1} a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2}\hat{\sigma}_{i,k-1} w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2}\hat{\sigma}_{i,k-1} w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until $\hat{\mu}_{i,k}$ and $\hat{\sigma}_{i,k}$ have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of 1e–6; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option:

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[\frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}^o, \mathbf{x}_{it} \beta + \sqrt{2} \sigma_{\nu} a_m^* \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it} \beta + \nu_i)$$

is well approximated by a polynomial. As panel size and ρ increase, the quadrature approximation can become less accurate. For large ρ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] [quadchk](#)) to verify the quadrature approximation used in this command, whichever approximation you choose.

References

- Honoré, B. E. 1992. Trimmed LAD and least squares estimation of truncated and censored regression models with fixed effects. *Econometrica* 60: 533–565.
- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.

Also see

- [XT] [xttobit postestimation](#) — Postestimation tools for `xttobit`
- [XT] [quadchk](#) — Check sensitivity of quadrature approximation
- [XT] [xtintreg](#) — Random-effects interval-data regression models
- [XT] [xtreg](#) — Fixed-, between-, and random-effects and population-averaged linear models
- [R] [tobit](#) — Tobit regression
- [U] [20 Estimation and postestimation commands](#)

Description

The following postestimation commands are available after `xttobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike’s and Schwarz’s Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

<i>statistic</i>	Description
Main	
<code>xb</code>	linear prediction assuming $\nu_i = 0$, the default
<code>stdp</code>	standard error of the linear prediction
<code>stdf</code>	standard error of the linear forecast
<code>pr0(<i>a</i>,<i>b</i>)</code>	$\Pr(a < y < b)$ assuming $\nu_i = 0$
<code>e0(<i>a</i>,<i>b</i>)</code>	$E(y \mid a < y < b)$ assuming $\nu_i = 0$
<code>ystar0(<i>a</i>,<i>b</i>)</code>	$E(y^*), y^* = \max\{a, \min(y, b)\}$ assuming $\nu_i = 0$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

where a and b may be numbers or variables; a missing ($a \geq .$) means $-\infty$, and b missing ($b \geq .$) means $+\infty$; see [U] 12.2.1 Missing values.

Menu for predict

Statistics > Postestimation > Predictions, residuals, etc.

Options for predict

Main

xb, the default, calculates the linear prediction.

stdp calculates the standard error of the prediction. It can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value.

stdf calculates the standard error of the forecast. This is the standard error of the point prediction for 1 observation. It is commonly referred to as the standard error of the future or forecast value. By construction, the standard errors produced by **stdf** are always larger than those produced by **stdp**; see *Methods and formulas* in [R] **regress**.

pr0(a,b) calculates estimates of $\Pr(a < y < b \mid \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, which is the probability that y would be observed in the interval (a,b) , given the current values of the predictors, \mathbf{x}_{it} , and given a zero random effect. In the discussion that follows, these two conditions are implied.

a and b may be specified as numbers or variable names; lb and ub are variable names;

pr0(20,30) calculates $\Pr(20 < y < 30)$;

pr0(lb,ub) calculates $\Pr(lb < y < ub)$; and

pr0(20, ub) calculates $\Pr(20 < y < ub)$.

a missing ($a \geq .$) means $-\infty$; **pr0(.,30)** calculates $\Pr(-\infty < y < 30)$;

pr0(lb ,30) calculates $\Pr(-\infty < y < 30)$ in observations for which $lb \geq .$
(and calculates $\Pr(lb < y < 30)$ elsewhere).

b missing ($b \geq .$) means $+\infty$; **pr0(20,.)** calculates $\Pr(+\infty > y > 20)$;

pr0(20, ub) calculates $\Pr(+\infty > y > 20)$ in observations for which $ub \geq .$
(and calculates $\Pr(20 < y < ub)$ elsewhere).

e0(a,b) calculates estimates of $E(y \mid a < y < b, \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, which is the expected value of y conditional on y being in the interval (a,b) , meaning that y is truncated. a and b are specified as they are for **pr0()**.

ystar0(a,b) calculates estimates of $E(y^* \mid \mathbf{x} = \mathbf{x}_{it}, \nu_i = 0)$, where $y^* = a$ if $y \leq a$, $y^* = b$ if $y \geq b$, and $y^* = y$ otherwise, meaning that y^* is the censored version of y . a and b are specified as they are for **pr0()**.

nooffset is relevant only if you specify **offset($varname$)** for **xttobit**. It modifies the calculations made by **predict** so that they ignore the offset variable; the linear prediction is treated as $\mathbf{x}_{it}\beta$ rather than $\mathbf{x}_{it}\beta + \text{offset}_{it}$.

Also see

[XT] **xttobit** — Random-effects tobit models

[U] 20 Estimation and postestimation commands

Syntax	Menu	Description	Options
Remarks and examples	Stored results	Methods and formulas	Acknowledgments
References	Also see		

Syntax

Levin–Lin–Chu test

```
xtunitroot llc varname [if] [in] [, LLC_options]
```

Harris–Tzavalis test

```
xtunitroot ht varname [if] [in] [, HT_options]
```

Breitung test

```
xtunitroot breitung varname [if] [in] [, Breitung_options]
```

Im–Pesaran–Shin test

```
xtunitroot ips varname [if] [in] [, IPS_options]
```

Fisher-type tests (combining *p*-values)

```
xtunitroot fisher varname [if] [in], {dfuller|pperron} lags(#)
[Fisher_options]
```

Hadri Lagrange multiplier stationarity test

```
xtunitroot hadri varname [if] [in] [, Hadri_options]
```

<i>LLC_options</i>	Description
<u>t</u> rend	include a time trend
<u>n</u> o <u>c</u> on <u>s</u> tant	suppress panel-specific means
<u>d</u> e <u>m</u> ean	subtract cross-sectional means
<u>lags</u> (<i>lag_spec</i>)	specify lag structure for augmented Dickey–Fuller (ADF) regressions
<u>k</u> ernel(<i>kernel_spec</i>)	specify method to estimate long-run variance

lag_spec is either a nonnegative integer or one of `aic`, `bic`, or `hqic` followed by a positive integer.
kernel_spec takes the form *kernel maxlags*, where *kernel* is one of `bartlett`, `parzen`, or `quadraticspectral` and *maxlags* is either a positive number or one of `nwest` or `llc`.

<i>HT_options</i>	Description
<code>trend</code>	include a time trend
<code>noconstant</code>	suppress panel-specific means
<code>demean</code>	subtract cross-sectional means
<code>altt</code>	make small-sample adjustment to T

<i>Breitung_options</i>	Description
<code>trend</code>	include a time trend
<code>noconstant</code>	suppress panel-specific means
<code>demean</code>	subtract cross-sectional means
<code>robust</code>	allow for cross-sectional dependence
<code>lags(#)</code>	specify lag structure for prewhitening

<i>IPS_options</i>	Description
<code>trend</code>	include a time trend
<code>demean</code>	subtract cross-sectional means
<code>lags(lag_spec)</code>	specify lag structure for ADF regressions

`lag_spec` is either a nonnegative integer or one of `aic`, `bic`, or `hqic` followed by a positive integer.

<i>Fisher_options</i>	Description
* <code>dfuller</code>	use ADF unit-root tests
* <code>pperron</code>	use Phillips–Perron unit-root tests
* <code>lags(#)</code>	specify lag structure for prewhitening
<code>demean</code>	subtract cross-sectional means
<code>dfuller_opts</code>	any options allowed by the <code>dfuller</code> command
<code>pperron_opts</code>	any options allowed by the <code>pperron</code> command

*Either `dfuller` or `pperron` is required.

*`lags(#)` is required.

<i>Hadri_options</i>	Description
<code>trend</code>	include a time trend
<code>demean</code>	subtract cross-sectional means
<code>robust</code>	allow for cross-sectional dependence
<code>kernel(kernel_spec)</code>	specify method to estimate long-run variance

`kernel_spec` takes the form `kernel [#]`, where `kernel` is one of `bartlett`, `parzen`, or `quadraticspectral` and `#` is a positive number.

`varname` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

Menu

Statistics > Longitudinal/panel data > Unit-root tests

Description

`xtunitroot` performs a variety of tests for unit roots (or stationarity) in panel datasets. The Levin–Lin–Chu (2002), Harris–Tzavalis (1999), Breitung (2000; Breitung and Das 2005), Im–Pesaran–Shin (2003), and Fisher-type (Choi 2001) tests have as the null hypothesis that all the panels contain a unit root. The Hadri (2000) Lagrange multiplier (LM) test has as the null hypothesis that all the panels are (trend) stationary. The top of the output for each test makes explicit the null and alternative hypotheses. Options allow you to include panel-specific means (fixed effects) and time trends in the model of the data-generating process.

Options

LLC_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

`lags(lag_spec)` specifies the lag structure to use for the ADF regressions performed in computing the test statistic.

Specifying `lags(#)` requests that `#` lags of the series be used in the ADF regressions. The default is `lags(1)`.

Specifying `lags(aic #)` requests that the number of lags of the series be chosen such that the Akaike information criterion (AIC) for the regression is minimized. `xtunitroot llc` will fit ADF regressions with 1 to `#` lags and choose the regression for which the AIC is minimized. This process is done for each panel so that different panels may use ADF regressions with different numbers of lags.

Specifying `lags(bic #)` is just like specifying `lags(aic #)`, except that the Bayesian information criterion (BIC) is used instead of the AIC.

Specifying `lags(hqic #)` is just like specifying `lags(aic #)`, except that the Hannan–Quinn information criterion is used instead of the AIC.

`kernel(kernel_spec)` specifies the method used to estimate the long-run variance of each panel's series. `kernel_spec` takes the form `kernel maxlags`. `kernel` is one of `bartlett`, `parzen`, or `quadraticspectral`. `maxlags` is a number, `nwest` to request the Newey and West (1994) bandwidth selection algorithm, or `llc` to request the lag truncation algorithm in Levin, Lin, and Chu (2002).

Specifying, for example, `kernel(bartlett 3)` requests the Bartlett kernel with 3 lags.

Specifying `kernel(bartlett nwest)` requests the Bartlett kernel with the maximum number of lags determined by the Newey and West bandwidth selection algorithm.

Specifying `kernel(bartlett llc)` requests the Bartlett kernel with a maximum lag determined by the method proposed in Levin, Lin, and Chu's (2002) article:

$$maxlags = \text{int} \left(3.21T^{1/3} \right)$$

where T is the number of observations per panel. This is the default.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

HT_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

`altt` requests that `xtunitroot` use $T - 1$ instead of T in the formulas for the mean and variance of the test statistic under the null hypothesis. When the number of time periods, T , is small (less than 10 or 15), the test suffers from severe size distortions when fixed effects or time trends are included; in these cases, using `altt` results in much improved size properties at the expense of significantly less power.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

Breitung_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

`lags(#)` specifies the number of lags used to remove higher-order autoregressive components of the series. The Breitung test assumes the data are generated by an AR(1) process; for higher-order processes, the first-differenced and lagged-level data are replaced by the residuals from regressions of those two series on the first $\#$ lags of the first-differenced data. The default is to not perform this prewhitening step.

`robust` requests a variant of the test that is robust to cross-sectional dependence.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

IPS_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`lags(lag_spec)` specifies the lag structure to use for the ADF regressions performed in computing the test statistic. With this option, `xtunitroot` reports Im, Pesaran, and Shin's (2003) W_{t-bar} statistic that is predicated on T going to infinity first, followed by N going to infinity. By default, no lags are included, and `xtunitroot` instead reports Im, Pesaran, and Shin's \bar{t} and \bar{Z}_{t-bar} statistics that assume T is fixed while N goes to infinity, as well as the $t-bar$ statistic and exact critical values that assume both N and T are fixed.

Specifying `lags(#)` requests that `#` lags of the series be used in the ADF regressions. By default, no lags are included.

Specifying `lags(aic #)` requests that the number of lags of the series be chosen such that the AIC for the regression is minimized. `xtunitroot llc` will fit ADF regressions with 1 to `#` lags and choose the regression for which the AIC is minimized. This process is done for each panel so that different panels may use ADF regressions with different numbers of lags.

Specifying `lags(bic #)` is just like specifying `lags(aic #)`, except that the BIC is used instead of the AIC.

Specifying `lags(hqic #)` is just like specifying `lags(aic #)`, except that the Hannan–Quinn information criterion is used instead of the AIC.

If you specify `lags(0)`, then `xtunitroot` reports the W_{t-bar} statistic instead of the Z_{t-bar} , \tilde{Z}_{t-bar} , and $t-bar$ statistics.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

Fisher_options

`dfuller` requests that `xtunitroot` conduct ADF unit-root tests on each panel by using the `dfuller` command. You must specify either the `dfuller` or the `pperron` option.

`pperron` requests that `xtunitroot` conduct Phillips–Perron unit-root tests on each panel by using the `pperron` command. You must specify either the `pperron` or the `dfuller` option.

`lags(#)` specifies the number of lags used to remove higher-order autoregressive components of the series. The Fisher test assumes the data are generated by an AR(1) process; for higher-order processes, the first-differenced and lagged-level data are replaced by the residuals from regressions of those two series on the first `#` lags of the first-differenced data. `lags(#)` is required.

`dfuller_opts` are any options accepted by the `dfuller` command, including `noconstant`, `trend`, `drift`, and `lags()`. Because `xtunitroot` calls `dfuller` quietly, the `dfuller` option `regress` has no effect. See [TS] [dfuller](#).

`pperron_opts` are any options accepted by the `pperron` command, including `noconstant`, `trend`, and `lags()`. Because `xtunitroot` calls `pperron` quietly, the `pperron` option `regress` has no effect. See [TS] [pperron](#).

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

Hadri_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`robust` requests a variant of the test statistic that is robust to heteroskedasticity across panels.

`kernel(kernel_spec)` requests a variant of the test statistic that is robust to serially correlated errors. `kernel_spec` specifies the method used to estimate the long-run variance of each panel's series. `kernel_spec` takes the form `kernel [#]`. Three kernels are supported: `bartlett`, `parzen`, and `quadraticspectral`.

Specifying, for example, `kernel(bartlett 3)` requests the Bartlett kernel with 3 lags.

If `#` is not specified, then 1 lag is used.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

Remarks and examples

Remarks are presented under the following headings:

Overview
Levin–Lin–Chu test
Harris–Tsavalis test
Breitung test
Im–Pesaran–Shin test
Fisher-type tests
Hadri LM test

Overview

We consider a simple panel-data model with a first-order autoregressive component:

$$y_{it} = \rho_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it} \quad (1)$$

where $i = 1, \dots, N$ indexes panels; $t = 1, \dots, T_i$ indexes time; y_{it} is the variable being tested; and ϵ_{it} is a stationary error term. The \mathbf{z}_{it} term can represent panel-specific means, panel-specific means and a time trend, or nothing, depending on the options specified to `xtunitroot`. By default, $\mathbf{z}_{it} = 1$, so that the term $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$ represents panel-specific means (fixed effects). If `trend` is specified, $\mathbf{z}'_{it} = (1, t)$ so that $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$ represents panel-specific means and linear time trends. For tests that allow it, specifying `noconstant` omits the $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$ term. The Im–Pesaran–Shin (`xtunitroot ips`), Fisher-type (`xtunitroot fisher`), and Hadri LM (`xtunitroot hadri`) tests allow unbalanced panels, while the remaining tests require balanced panels so that $T_i = T$ for all i .

Panel unit-root tests are used to test the null hypothesis $H_0: \rho_i = 1$ for all i versus the alternative $H_a: \rho_i < 1$. Depending on the test, H_a may hold, for one i , a fraction of all i or all i ; the output of the respective test precisely states the alternative hypothesis. Equation (1) is often written as

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it} \quad (1')$$

so that the null hypothesis is then $H_0: \phi_i = 0$ for all i versus the alternative $H_a: \phi_i < 0$.

The Hadri LM test for panel stationarity instead assumes the null hypothesis that all panels are stationary versus the alternative that at least some of the panels contain unit roots. We discuss the Hadri LM test in detail later, though for now our remarks focus on tests whose null hypothesis is that the panels contain unit roots.

The various panel unit-root tests implemented by `xtunitroot` differ in several key aspects. First, the Levin–Lin–Chu (`xtunitroot llc`), Harris–Tsavalis (`xtunitroot ht`), and Breitung (`xtunitroot breitung`) tests make the simplifying assumption that all panels share the same autoregressive parameter so that $\rho_i = \rho$ for all i . The other tests implemented by `xtunitroot`, however, allow the autoregressive parameter to be panel specific. Maddala and Wu (1999) provide an example of testing whether countries' economic growth rates converge to a long-run value. Imposing the restriction that $\rho_i = \rho$ for all i implies that the rate of convergence would be the same for all countries, an implication that is too restrictive in practice.

Second, the various tests make differing assumptions about the rates at which the number of panels, N , and the number of time periods, T , tend to infinity or whether N or T is fixed. For microeconomic panels of firms, for example, increasing the sample size would involve gathering data on more firms while holding the number of time periods fixed; here N tends to infinity whereas T is fixed. In a macroeconomic analysis of OECD countries, one would typically assume that N is fixed whereas T tends to infinity.

Related to the previous point, the size of one’s sample will in large part determine which test is most appropriate in a given situation. If a dataset has a small number of panels and a large number of time periods, then a panel unit-root test that assumes that N is fixed or that N tends to infinity at a slower rate than T will likely perform better than one that is designed for cases where N is large.

Hlouskova and Wagner (2006) provide a good overview of the types of panel unit-root tests available with `xtunitroot`, and they present exhaustive Monte Carlo simulations examining the tests’ performance. Baltagi (2013, chap. 12) also concisely discusses the tests implemented by `xtunitroot`.

The following table summarizes some of the key differences among the various tests:

Test	Options	Asymptotics	ρ under H_a	Panels
LLC	<code>noconstant</code>	$\sqrt{N}/T \rightarrow 0$	common	balanced
LLC		$N/T \rightarrow 0$	common	balanced
LLC	<code>trend</code>	$N/T \rightarrow 0$	common	balanced
HT	<code>noconstant</code>	$N \rightarrow \infty, T$ fixed	common	balanced
HT		$N \rightarrow \infty, T$ fixed	common	balanced
HT	<code>trend</code>	$N \rightarrow \infty, T$ fixed	common	balanced
Breitung	<code>noconstant</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
Breitung		$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
Breitung	<code>trend</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
IPS		$N \rightarrow \infty, T$ fixed or N and T fixed	panel-specific	unbalanced
IPS	<code>trend</code>	$N \rightarrow \infty, T$ fixed or N and T fixed	panel-specific	unbalanced
IPS	<code>lags()</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	panel-specific	unbalanced
IPS	<code>trend lags()</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	panel-specific	unbalanced
Fisher-type		$T \rightarrow \infty, N$ finite or infinite	panel-specific	unbalanced
Hadri LM		$(T, N) \rightarrow_{\text{seq}} \infty$	(not applicable)	balanced
Hadri LM	<code>trend</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	(not applicable)	balanced

The first column identifies the test procedure, where we use LLC to denote the Levin–Lin–Chu test, HT to denote the Harris–Tsavalis test, and IPS to denote the Im–Pesaran–Shin test. The second column indicates the deterministic components included in (1) or (1’). The column labeled “Asymptotics” indicates the behavior of the number of panels, N , and time periods, T , required for the test statistic to have a well-defined asymptotic distribution. For example, the LLC test without the `noconstant`

option requires that T grow at a faster rate than N so that N/T approaches zero; with the `noconstant` option, we need only for T to grow faster than the square root of N (so T could grow more slowly than N).

The HT tests and the IPS tests without accommodations for serial correlation assume that the number of time periods, T , is fixed, whereas N tends to infinity; `xtunitroot` also reports critical values for the IPS tests that are valid in finite samples (where N and T are fixed).

Many of the tests are justified using sequential limit theory, which we denote as $(T, N) \rightarrow_{\text{seq}} \infty$. First, the time dimension goes to infinity, and then the number of panels goes to infinity. As a practical matter, these tests work best with “large” T and at least “moderate” N . See [Phillips and Moon \(2000\)](#) for an introduction to asymptotics that depend on both N and T and their relation to nonstationary panels. [Phillips and Moon \(1999\)](#) contains a more technical discussion of “multi-indexed” asymptotics.

The fourth column refers to the parameter ρ_i in (1) and ϕ_i in (1'). As we mentioned previously, some tests assume that all panels have the same autoregressive parameter under the alternative hypothesis of stationarity (denoted “common” in the table), while others allow for panel-specific autoregressive parameters (denoted “panel-specific” in the table). The Hadri LM tests are not framed in terms of an equation like (1) or (1'), so the distinction based on ρ is not applicable.

The final column indicates whether the panel dataset must be strongly balanced, meaning each panel has the same number of observations covering the same time span. Except for the Fisher tests, all the tests require that there be no gaps in any panel’s series.

We now discuss each test in turn.

Levin–Lin–Chu test

The starting point for the Levin–Lin–Chu (LLC) test is (1') with the restriction that all panels share a common autoregressive parameter. In a regression model like (1), ϵ_{it} is likely to be plagued by serial correlation, so to mitigate this problem, LLC augment the model with additional lags of the dependent variable:

$$\Delta y_{it} = \phi y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \sum_{j=1}^p \theta_{ij} \Delta y_{i,t-j} + u_{it} \quad (2)$$

The number of lags, p , can be specified using the `lags()` option, or you can have `xtunitroot llc` select the number of lags that minimizes one of several information criteria. The LLC test assumes that ϵ_{it} is independently distributed across panels and follows a stationary invertible autoregressive moving-average process for each panel. By including sufficient lags of $\Delta y_{i,t}$ in (2), u_{it} will be white noise; the test does not require u_{it} to have the same variance across panels.

Under the null hypothesis of a unit root, y_{it} is nonstationary, so a standard OLS regression t statistic for ϕ will have a nonstandard distribution that depends in part on the specification of the \mathbf{z}_{it} term. Moreover, the inclusion of a fixed-effect term in a dynamic model like (2) causes the OLS estimate of ϕ to be biased toward zero; see [Nickell \(1981\)](#). The LLC method produces a bias-adjusted t statistic, which the authors denote as t_{δ}^* , that has an asymptotically normal distribution.

The LLC test without panel-specific intercepts or time trends, requested by specifying the `noconstant` option with `xtunitroot llc`, is justified asymptotically if $\sqrt{N}/T \rightarrow 0$, allowing the time dimension T to grow more slowly than the cross-sectional dimension N ; [LLC \(2002\)](#) mention that this assumption is particularly relevant for panel datasets typically encountered in microeconomic applications.

If model (2) includes panel-specific means (the default for `xtunitroot llc`) or time trends (requested with the `trend` option), then you must assume that $N/T \rightarrow 0$ for the t_{δ}^* statistic to have

an asymptotically standard normal distribution. This implies that the time dimension, T , must grow faster than the cross-sectional dimension, N , a situation more plausible with macroeconomic datasets.

LLC (2002) recommend using their test with panels of “moderate” size, which they describe as having between 10 and 250 panels and 25 to 250 observations per panel. Baltagi (2013, sec. 12.2.3) mentions that the requirement $N/T \rightarrow 0$ implies that N should be small relative to T .

□ Technical note

Panel unit-root tests have frequently been used to test the purchasing power parity (PPP) hypothesis. We use a PPP dataset to illustrate the `xtunitroot` command, but understanding PPP is not required to understand how these tests are applied. Here we outline PPP and explain how to test it using panel unit-root tests; uninterested readers can skip the remainder of this technical note. Our discussion and examples are motivated by those in Oh (1996) and Patterson (2000, chap. 13). Also see Rogoff (1996) for a broader introduction to PPP.

The PPP hypothesis is based on the Law of One Price, which stipulates that the price of a tradeable good will be the same everywhere. Absolute PPP stipulates that the nominal exchange rate, E , is

$$E = \frac{P}{P^*}$$

where P is the price of a basket of goods in the home country and P^* is the price of the same basket in the foreign country. The exchange rate, E , indicates the price of a foreign currency in terms of our “home” currency or, equivalently, how many units of the home currency are needed to buy one unit of the foreign currency.

Now consider the real exchange rate, λ , which tells us the prices of goods and services—things we actually consume—in a foreign country relative to their prices at home. We have

$$\lambda = \frac{EP^*}{P} \tag{3}$$

λ in general does not equal unity for many reasons, including the fact that not all goods are tradeable across countries (haircuts being the textbook example), trade barriers such as tariffs and quotas, differences among countries in how price indices are constructed, and the Harrod–Balassa–Samuelson effect, which links productivity and price levels; see Obstfeld and Rogoff (1996, 210–216).

Taking logs of both sides of (3), we have

$$y \equiv \ln \lambda = \ln E + \ln P^* - \ln P$$

PPP holds only if the real exchange rate reverts to its equilibrium value over time. Thus, to test for PPP, we test whether y contains a unit root. If y does contain a unit root, we reject PPP.

The dataset `pennxrate.dta` contains real exchange-rate data based on the Penn World Table version 6.2 (Heston, Summers, and Aten 2006). The data are a balanced panel consisting of 151 countries observed over 34 years, from 1970 through 2003. The United States was treated as the domestic country and is therefore not included. The variable `lnrxrate` contains the log of the real exchange rate and is the variable on which we conduct panel unit-root tests in the examples.

Two indicator variables are included in the dataset as well. The variable `oecd` flags 27 countries aside from the United States that are members of the Organization for Economic Cooperation and Development (OECD). (The Czech Republic and the Slovak Republic are excluded because they did not become independent countries until 1993.) The variable `g7` flags the six countries aside from the United States that are members of the Group of Seven (G7) nations.

□

► Example 1

The dataset `pennxr.dta` contains real exchange-rate data for a panel of countries observed over 34 years. Here we use the LLC test to determine whether the series `lnrxrate`, the log of real exchange rates, contains a unit root for six nations that are currently in the G7 group of advanced economies. We do not have any reason to believe `lnrxrate` should exhibit a global trend, so we do not include the `trend` option.

Looking at (2), we have no a priori knowledge of the number of lags, p , needed to ensure that u_{it} is white noise, so we let `xtunitroot` choose the number of lags for each panel by minimizing the AIC, subject to a maximum of 10 lags.

We type

```
. use http://www.stata-press.com/data/r13/pennxr
. xtunitroot llc lnrxrate if g7, lags(aic 10)
Levin-Lin-Chu unit-root test for lnrxrate
```

Ho: Panels contain unit roots	Number of panels =	6
Ha: Panels are stationary	Number of periods =	34
AR parameter: Common	Asymptotics: N/T ->	0
Panel means: Included		
Time trend: Not included		
ADF regressions: 1.00 lags average (chosen by AIC)		
LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)		

	Statistic	p-value
Unadjusted t	-6.7538	
Adjusted t*	-4.0277	0.0000

The header of the output summarizes the exact specification of the test and dataset. Because we did not specify the `noconstant` option, the test allowed for panel-specific means. On average, $p = 1$ lag of the dependent variable of (2) were included as regressors in the ADF regressions. By default, `xtunitroot` estimated the long-run variance of $\Delta \ln rxrate_{it}$ by using a Bartlett kernel with an average of 10 lags.

The LLC bias-adjusted test statistic $t_{\delta}^* = -4.0277$ is significantly less than zero ($p < 0.00005$), so we reject the null hypothesis of a unit-root [that is, that $\phi = 0$ in (2)] in favor of the alternative that `lnrxrate` is stationary (that is, that $\phi < 0$). This conclusion supports the PPP hypothesis.

Labeled “Unadjusted t” in the output is a conventional t statistic for testing $H_0: \phi = 0$. When the model does not include panel-specific means or trends, this test statistic has a standard normal limiting distribution and its p -value is shown in the output; the unadjusted statistic, t_{δ} , diverges to negative infinity if trends or panel-specific constants are included, so a p -value is not displayed in those cases.

Because the G7 economies have many similarities, our results could be affected by cross-sectional correlation in real exchange rates; O’Connell’s (1998) results showed that the LLC test exhibits severe size distortions in the presence of cross-sectional correlation. LLC (2002) suggested removing cross-sectional averages from the data to help control for this correlation. We can do this by specifying the `demean` option to `xtunitroot`:


```
. xtunitroot llc lnrxrate if g7, lags(aic 10) demean
Levin-Lin-Chu unit-root test for lnrxrate
```

Ho: Panels contain unit roots	Number of panels =	6
Ha: Panels are stationary	Number of periods =	34
AR parameter: Common	Asymptotics: N/T -> 0	
Panel means: Included		
Time trend: Not included	Cross-sectional means removed	
ADF regressions: 1.50 lags average (chosen by AIC)		
LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)		

	Statistic	p-value
Unadjusted t	-5.5473	
Adjusted t*	-2.0813	0.0187

Once we control for cross-sectional correlation by removing cross-sectional means, we can no longer reject the null hypothesis of a unit root at the 1% significance level, though we can reject at the 5% level.



Here we chose the number of lags based on the AIC criterion in an admission that we do not know the true number of lags to include in (2). However, the test statistics are derived under the assumption that the lag order, p , is known. If we happen to choose the wrong number of lags, then the distribution of the test statistic will depart from its expected distribution that assumes p is known.

Harris–Tsavalis test

In many datasets, particularly in microeconomics, the time dimension, T , is small, so tests whose asymptotic properties are established by assuming that T tends to infinity can lead to incorrect inference. HT (1999) derived a unit-root test that assumes that the time dimension, T , is fixed. Their simulation results suggest that the test has favorable size and power properties for N greater than 25, and they report (p. 213) that power improves faster as T increases for a given N than when N increases for a given T .

The HT test statistic is based on the OLS estimator, ρ , in the regression model

$$y_{it} = \rho y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it} \tag{4}$$

where the term $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$ allows for panel-specific means and trends and was discussed in [Overview](#). Harris and Tsavalis assume that ϵ_{it} is independent and identically distributed (i.i.d.) normal with constant variance across panels. Because of the bias induced by the inclusion of the panel means and time trends in this model, the expected value of the OLS estimator is not equal to unity under the null hypothesis. Harris and Tsavalis derived the mean and standard error of $\hat{\rho}$ for (4) under the null hypothesis $H_0: \rho = 1$ when neither panel-specific means nor time trends are included (requested with the `noconstant` option), when only panel-specific means are included (the default), and when both panel-specific means and time trends are included (requested with the `trend` option). The asymptotic distribution of the test statistic is justified as $N \rightarrow \infty$, so you should have a relatively large number of panels when using this test. Notice that, like the LLC test, the HT test assumes that all panels share the same autoregressive parameter.

► Example 2

Because the HT test is designed for cases where N is relatively large, here we test whether the series `lnrxrate` contains a unit root using all 151 countries in our dataset. We will again remove cross-sectional means to help control for contemporaneous correlation. We type

```
. xtunitroot ht lnrxrate, demean
Harris-Tzavalis unit-root test for lnrxrate
```

Ho: Panels contain unit roots	Number of panels =	151
Ha: Panels are stationary	Number of periods =	34
AR parameter: Common	Asymptotics: N ->	Infinity
Panel means: Included	T	Fixed
Time trend: Not included	Cross-sectional means	removed

	Statistic	z	p-value
rho	0.8184	-13.1239	0.0000

Here we strongly reject the null hypothesis of a unit root, again finding support for PPP. The point estimate of ρ in (4) is 0.8184, and the z statistic is -13.12 .



Can we directly compare the results from the LLC and HT tests? We used a subset of the data for the LLC test but used all the data for the HT test. That leads to the obvious answer that no, our results are not entirely comparable. However, a more subtle issue regarding the asymptotic properties of the tests also warrants caution when comparing results.

The LLC test assumes that $N/T \rightarrow 0$, so N should be small relative to T . Moreover, with our exchange-rate dataset, we are much more likely to be able to add more years of data rather than add more countries, because the number of countries in the world is for the most part fixed. Hence, assuming T grows faster than N is certainly plausible.

On the other hand, the HT test assumes that T is fixed whereas N goes to infinity. Is that assumption plausible for our dataset? As we just mentioned, T likely grows faster than N here, so using a test that assumes T is fixed whereas N grows is hard to justify with our dataset.

In short, when selecting a panel unit-root test, you must consider the relative sizes of N and T and the relative speeds at which they tend to infinity or whether either N or T is fixed.

Breitung test

Both the LLC and HT tests take the approach of first fitting a regression model and subsequently adjusting the autoregressive parameter or its t statistic to compensate for the bias induced by having a dynamic regressor and fixed effects in the model. The [Breitung \(2000; Breitung and Das 2005\)](#) test takes a different tact, adjusting the data before fitting a regression model so that bias adjustments are not needed.

In the LLC test, additional lags of the dependent variable could be included in (2) to control for serial correlation. The Breitung procedure instead allows for a prewhitening of the series before computing the test. If the `trend` option is not specified, we regress Δy_{it} and $y_{i,t-1}$ on $\Delta y_{i,t-1}, \dots, \Delta y_{i,t-p}$ and use the residuals from those regressions in place of $\Delta y_{i,t}$ and $y_{i,t-1}$ in computing the test. You specify the number of lags, p , to use by specifying `lags(#)`. If the `trend` option is specified, then the Breitung method uses a different prewhitening procedure that involves fitting only one (instead of two) preliminary regressions; see [Methods and formulas](#) for details.

Monte Carlo simulations by [Breitung \(2000\)](#) show that bias-corrected statistics such as LLC's t_{δ}^* suffer from low power, particularly against alternative hypotheses with autoregressive parameters near one and when panel-specific effects are included. In contrast, the [Breitung \(2000\)](#) test statistic exhibits much higher power in these cases. Moreover, the Breitung test has good power even with small datasets ($N = 25$, $T = 25$), though the power of the test appears to deteriorate when T is fixed and N is increased.

The Breitung test assumes that the error term ϵ_{it} is uncorrelated across both i and t . `xtunitroot breitung` optionally also reports a version of the statistic based on [Breitung and Das \(2005\)](#) that is robust to cross-sectional correlation.

➤ Example 3

Here we test whether `lnrxrate` contains a unit root for the subset of 27 OECD countries in our dataset. We will use the `robust` option to obtain a test statistic that is robust to cross-sectional correlation, so we will not subtract the cross-sectional means via the `demean` option. We type

```
. xtunitroot breitung lnrxrate if oecd, robust
Breitung unit-root test for lnrxrate
-----
Ho: Panels contain unit roots          Number of panels =      27
Ha: Panels are stationary              Number of periods =     34
AR parameter: Common                  Asymptotics: T,N -> Infinity
Panel means: Included                  sequentially
Time trend: Not included              Prewhitening: Not performed
-----
               Statistic      p-value
-----
lambda*         -1.6794         0.0465
-----
* Lambda robust to cross-sectional correlation
```

We can reject the null of a unit root at the 5% level but not at the 1% level.

◀

Im–Pesaran–Shin test

All the tests we have discussed thus far assume that all panels share a common autoregressive parameter, ρ . Cultural, institutional, and other factors make such an assumption tenuous for both macro- and microeconomic panel datasets. [IPS \(2003\)](#) developed a set of tests that relax the assumption of a common autoregressive parameter. Moreover, the IPS test does not require balanced datasets, though there cannot be gaps within a panel. The starting point for the IPS test is a set of Dickey–Fuller regressions of the form

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \epsilon_{it} \tag{5}$$

Notice that here ϕ is panel-specific, indexed by i , whereas in (2), ϕ is constant. Im, Pesaran, and Shin assume that ϵ_{it} is independently distributed normal for all i and t , and they allow ϵ_{it} to have heterogeneous variances σ_i^2 across panels.

As described by [Maddala and Wu \(1999\)](#), one way to view the key difference between the IPS and LLC tests is that here we fit (5) to each panel separately and average the resulting t statistics, whereas in the LLC test we pool the data before fitting an equation such as (2) (thus we impose a common autoregressive parameter) and compute a test statistic based on the pooled regression results.

Under the null hypothesis that all panels contain a unit root, we have $\phi_i = 0$ for all i . The alternative is that the fraction of panels that follow stationary processes is nonzero; that is, as N tends to infinity, the fraction N_1/N converges to a nonzero value, where N_1 is the number of panels that are stationary.

Whether you allow for serially correlated errors determines the test statistics produced, and because there are substantive differences in the output, we consider the serially uncorrelated and serially correlated cases separately. First, we consider the serially uncorrelated case, which `xtunitroot` assumes when you do not specify the `lags()` option.

The IPS test allowing for heterogeneous panels with serially uncorrelated errors assumes that the number of time periods, T , is fixed; `xtunitroot ips` produces statistics both for the case where N is fixed and for the case where $N \rightarrow \infty$. Under the null hypothesis of a unit root, the usual t statistic, t_i , for testing $H_0: \phi_i = 0$ in (5) does not have a mean of zero. For the case where N is fixed, IPS used simulation to tabulate “exact” critical values for the average of the t_i statistics when the dataset is balanced; these critical values are not available with unbalanced datasets. The critical values are “exact” only when the error term is normally distributed and when T corresponds to one of the sample sizes used in their simulation studies. For other values of T , `xtunitroot ips` linearly interpolates the values in IPS (2003, table 2).

For the case where $N \rightarrow \infty$, they used simulation to tabulate the mean and variance of t_i for various values of T under the null hypothesis and showed that a bias-adjusted average of the t_i ’s has a standard normal limiting distribution. We illustrate the test with an example.

► Example 4

Here we test whether `lnrxrate` contains a unit root for the subset of OECD countries. We type

```
. xtunitroot ips lnrxrate if oecd, demean
Im-Pesaran-Shin unit-root test for lnrxrate
```

Ho: All panels contain unit roots	Number of panels =	27
Ha: Some panels are stationary	Number of periods =	34
AR parameter: Panel-specific	Asymptotics: T,N ->	Infinity
Panel means: Included		sequentially
Time trend: Not included	Cross-sectional means	removed
ADF regressions: No lags included		

	Statistic	p-value	Fixed-N exact critical values		
			1%	5%	10%
t-bar	-3.1327		-1.810	-1.730	-1.680
t-tilde-bar	-2.5771				
Z-t-tilde-bar	-7.3911	0.0000			

As with the other unit-root tests available with `xtunitroot`, the header of the output contains a summary of the dataset’s dimensions and the null and alternative hypotheses. First, consider the statistic labeled `t-bar`, which IPS denote as $t\text{-}bar_{NT}$. This statistic is appropriate when you assume that both N and T fixed; exact critical values reported in IPS (2003) are reported immediately to its right. Here, because $t\text{-}bar_{NT}$ is less than even its 1% critical value, we strongly reject the null hypothesis that all series contain a unit root in favor of the alternative that a nonzero fraction of the panels represent stationary processes.

The statistic labeled `t-tilde-bar` is IPS’s $\tilde{t}\text{-}bar_{NT}$ statistic and is similar to the $t\text{-}bar_{NT}$ statistic, except that a different estimator of the Dickey–Fuller regression error variance is used. A standardized version of this statistic, $Z_{\tilde{t}\text{-}bar}$, is labeled `Z-t-tilde-bar` in the output and has an asymptotic standard

normal distribution. Here the p -value corresponding to $Z\text{-}t\text{-tilde-bar}$ is essentially zero, so we strongly reject the null that all series contain a unit root.



□ Technical note

Just as the $Z_{t\text{-}bar}$ statistic corresponds to $\tilde{t}\text{-}bar_{NT}$, IPS present a $Z_{t\text{-}bar}$ statistic corresponding to $t\text{-}bar_{NT}$. However, the $Z_{t\text{-}bar}$ statistic does not have an asymptotic normal distribution, and so it is not presented in the output. $Z_{t\text{-}bar}$ is available in the stored results as `r(zt)`.



When serial correlation is present, we augment the Dickey–Fuller regression with further lags of the dependent variable:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \sum_{j=1}^p \Delta y_{i,t-j} + \epsilon_{it} \tag{6}$$

where the number of lags, p , is specified using the `lags()` option, and if the `trend` option is specified, we also include a time trend with panel-specific slope. You can either specify a number or have `xtunitroot` choose the number of lags for each panel by minimizing an information criterion. Here `xtunitroot` produces the IPS $W_{t\text{-}bar}$ statistic, which has an asymptotically standard normal distribution as $T \rightarrow \infty$ followed by $N \rightarrow \infty$. As a practical matter, this means you should have a reasonably large number of both time periods and panels to use this test.

Part of the computation of the $W_{t\text{-}bar}$ statistic involves retrieving expected values and variances of the t statistic for β_i in (6) in table 3 of IPS (2003). Because expected values have not been computed beyond $p = 8$ lags in (6), you cannot request more than 8 lags in the `lags()` option.

► Example 5

We again test whether `lnrxrate` contains a unit root for the subset of OECD countries, except we allow for serially correlated errors. We will choose the number of lags for the ADF regressions by minimizing the AIC criterion, subject to a maximum of 8 lags. We type

```
. xtunitroot ips lnrxrate if oecd, lags(aic 8) demean
Im-Pesaran-Shin unit-root test for lnrxrate
```

Ho: All panels contain unit roots	Number of panels =	27
Ha: Some panels are stationary	Number of periods =	34
AR parameter: Panel-specific	Asymptotics: T,N ->	Infinity
Panel means: Included		sequentially
Time trend: Not included	Cross-sectional means removed	
ADF regressions: 1.48 lags average (chosen by AIC)		
	Statistic	p-value
W-t-bar	-7.3075	0.0000



Fisher-type tests

In our discussion of the IPS test, we intimated that the test statistics could be viewed as averages of bias-adjusted t statistics for each panel. As [Maddala and Wu \(1999, 635\)](#) describe the IPS test, “... the IPS test is a way of combining the evidence on the unit-root hypothesis from the N unit-root tests performed on the N cross-section units.” Fisher-type panel unit-root tests make this approach explicit.

Meta-analysis, frequently used in biostatistics and medical sciences, is the combination of results from multiple studies designed to test a similar hypothesis in order to yield a more decisive conclusion. One type of meta-analysis, first proposed by R. A. Fisher, combines the p -values from independent tests to obtain an overall test statistic and is frequently called a Fisher-type test. See [Whitehead \(2002, sec. 9.8\)](#) for an introduction. In the context of panel data unit-root tests, we perform a unit-root test on each panel’s series separately, then combine the p -values to obtain an overall test of whether the panel series contains a unit root.

`xtunitroot fisher` performs either ADF or Phillips–Perron unit-root tests on each panel depending on whether you specify the `dfuller` or `pperron` option. The actual tests are conducted by the `dfuller` and `pperron` commands, and you can specify to `xtunitroot fisher` any options those commands take; see [\[TS\] dfuller](#) and [\[TS\] pperron](#).

`xtunitroot fisher` combines the p -values from the panel-specific unit-root tests using the four methods proposed by [Choi \(2001\)](#). Three of the methods differ in whether they use the inverse χ^2 , inverse-normal, or inverse-logit transformation of p -values, and the fourth is a modification of the inverse χ^2 transformation that is suitable for when N tends to infinity. The inverse-normal and inverse-logit transformations can be used whether N is finite or infinite.

The null hypothesis being tested by `xtunitroot fisher` is that all panels contain a unit root. For a finite number of panels, the alternative is that at least one panel is stationary. As N tends to infinity, the number of panels that do not have a unit root should grow at the same rate as N under the alternative hypothesis.

► Example 6

Here we test for a unit root in `lnrxrate` using all 151 countries in our sample. We will use the ADF test. As before, we do not include a trend in real exchange rates and will therefore not specify the `trend` option. However, because the mean real exchange rate for any country is nonzero, we will specify the `drift` option. We will use two lags in the ADF regressions, and we will remove cross-sectional means by using `demean`. We type


```
. xtunitroot fisher lnrxrate, dfuller drift lags(2) demean
```

Fisher-type unit-root test for lnrxrate
Based on augmented Dickey-Fuller tests

Ho: All panels contain unit roots

Ha: At least one panel is stationary

AR parameter: Panel-specific

Panel means: Included

Time trend: Not included

Drift term: Included

Number of panels = 151

Number of periods = 34

Asymptotics: T -> Infinity

Cross-sectional means removed

ADF regressions: 2 lags

	Statistic	p-value
Inverse chi-squared(302) P	975.9130	0.0000
Inverse normal Z	-19.6183	0.0000
Inverse logit t(759) L*	-20.9768	0.0000
Modified inv. chi-squared Pm	27.4211	0.0000

P statistic requires number of panels to be finite.

Other statistics are suitable for finite or infinite number of panels.

All four of the tests strongly reject the null hypothesis that all the panels contain unit roots. Choi’s (2001) simulation results suggest that the inverse normal Z statistic offers the best trade-off between size and power, and he recommends using it in applications. We have observed that the inverse logit L^* test typically agrees with the Z test. Under the null hypothesis, Z has a standard normal distribution and L^* has a t distribution with $5N + 4$ degrees of freedom. Low values of Z and L^* cast doubt on the null hypothesis.

When the number of panels is finite, the inverse $\chi^2 P$ test is applicable; this statistic has a χ^2 distribution with $2N$ degrees of freedom, and large values are cause to reject the null hypothesis. Under the null hypothesis, as $T \rightarrow \infty$ followed by $N \rightarrow \infty$, P tends to infinity so that P has a degenerate limiting distribution. For large panels, Choi (2001) therefore proposes the modified inverse $\chi^2 P_m$ test which converges to a standard normal distribution; a large value of P_m casts doubt on the null hypothesis. Choi’s simulation results do not reveal a specific value of N over which P_m should be preferred to P , though he mentions that $N = 100$ is still too small for P_m to have an approximately normal distribution.

◄

Hadri LM test

All the tests we have discussed so far take as the null hypothesis that the series contains a unit root. Classical statistical methods are designed to reject the null hypothesis only when the evidence against the null is sufficiently overwhelming. However, because unit-root tests typically are not very powerful against alternative hypotheses of somewhat persistent but stationary processes, reversing roles and testing the null hypothesis of stationarity against the alternative of a unit root is appealing. For pure time series, the KPSS test of Kwiatkowski et al. (1992) is one such test.

The Hadri (2000) LM test uses panel data to test the null hypothesis that the data are stationary versus the alternative that at least one panel contains a unit root. The test is designed for cases with large T and moderate N . The motivation for the test is straightforward. Suppose we include a panel-specific time trend (using the `trend` option with `xtunitroot hadri`) and write our series, y_{it} , as

$$y_{it} = r_{it} + \beta_i t + \epsilon_{it}$$

where r_{it} is a random walk,

$$r_{it} = r_{i,t-1} + u_{it}$$

and ϵ_{it} and u_{it} are zero-mean i.i.d. normal errors. If the variance of u_{it} were zero, then r_{it} would collapse to a constant; y_{it} would therefore be trend stationary. Using this logic, the Hadri LM test tests the hypothesis

$$H_0: \lambda = \frac{\sigma_u^2}{\sigma_\epsilon^2} = 0 \qquad \text{versus} \qquad H_a: \lambda > 0$$

Two options to `xtunitroot hadri` allow you to relax the assumption that ϵ_{it} is i.i.d., though normality is still required. You can specify the `robust` option to obtain a variant of the test that is robust to heteroskedasticity across panels, or you can specify `kernel()` to obtain a variant that is robust to serial correlation and heteroskedasticity. Asymptotically, the Hadri LM test is justified as $T \rightarrow \infty$ followed by $N \rightarrow \infty$. As a practical matter, [Hadri \(2000\)](#) recommends this test for “large” T and “moderate” N .

► Example 7

We now test the null hypothesis that `lnrxrate` is stationary for the subset of OECD countries. To control for serial correlation, we will use a Bartlett kernel with 5 lags. We type

```
. xtunitroot hadri lnrxrate if oecd, kernel(bartlett 5) demean
Hadri LM test for lnrxrate
```

Ho: All panels are stationary	Number of panels =	27
Ha: Some panels contain unit roots	Number of periods =	34
Time trend:	Not included	Asymptotics: T, N -> Infinity
Heteroskedasticity:	Robust	sequentially
LR variance:	Bartlett kernel, 5 lags	Cross-sectional means removed

	Statistic	p-value
z	9.6473	0.0000

We strongly reject the null hypothesis that all panels’ series are stationary in favor of the alternative that at least one of them contains a unit root. In contrast, the previous examples generally rejected the null hypothesis that all series contain unit roots in favor of the alternative that at least some are stationary. For cautionary remarks on the use of panel unit-root tests in the examination of PPP, see, for example, [Banerjee, Marcellino, and Osbat \(2005\)](#). In short, our results are qualitatively quite similar to those reported in the literature, though [Banerjee, Marcellino, and Osbat](#) argue that because of cross-unit cointegration and long-run relationships among countries, panel unit-root tests quite often reject the null hypothesis even when true.



Stored results

`xtunitroot llc` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(sig_adj)</code>	standard deviation adjustment
<code>r(mu_adj)</code>	mean adjustment
<code>r(delta)</code>	pooled estimate of δ
<code>r(se_delta)</code>	pooled standard error of $\hat{\delta}$
<code>r(Var_ep)</code>	variance of whitened differenced series
<code>r(sbar)</code>	mean of ratio of long-run to innovation standard deviations
<code>r(ttilde)</code>	observations per panel after lagging and differencing
<code>r(td)</code>	unadjusted t_δ statistic
<code>r(p_td)</code>	p -value for t_δ
<code>r(tds)</code>	adjusted t_δ^* statistic
<code>r(p_tds)</code>	p -value for t_δ^*
<code>r(hac_lags)</code>	lags used in HAC variance estimator
<code>r(hac_lagm)</code>	average lags used in HAC estimator
<code>r(adf_lags)</code>	lags used in ADF regressions
<code>r(adf_lagm)</code>	average lags used in ADF regressions

Macros

<code>r(test)</code>	<code>llc</code>
<code>r(hac_kernel)</code>	kernel used in HAC variance estimator
<code>r(hac_method)</code>	HAC lag-selection algorithm
<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(demean)</code>	<code>demean</code> , if the data were demeaned
<code>r(deterministics)</code>	<code>noconstant</code> , <code>constant</code> , or <code>trend</code>

`xtunitroot ht` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(rho)</code>	estimated ρ
<code>r(Var_rho)</code>	variance of ρ under H_0
<code>r(mean_rho)</code>	mean of ρ under H_0
<code>r(z)</code>	z statistic
<code>r(p)</code>	p -value

Macros

<code>r(test)</code>	<code>ht</code>
<code>r(demean)</code>	<code>demean</code> , if the data were demeaned
<code>r(deterministics)</code>	<code>noconstant</code> , <code>constant</code> , or <code>trend</code>
<code>r(altt)</code>	<code>altt</code> , if <code>altt</code> was specified

xtunitroot breitung stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(lambda)</code>	test statistic λ
<code>r(lrobust)</code>	robust test statistic λ_R
<code>r(p)</code>	p -value for λ
<code>r(p_lrobust)</code>	p -value for λ_R
<code>r(lags)</code>	lags used for prewhitening

Macros

<code>r(test)</code>	breitung
<code>r(demean)</code>	demean , if the data were demeaned
<code>r(robust)</code>	robust , if specified
<code>r(deterministics)</code>	noconstant , constant , or trend

xtunitroot ips stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(tbar)</code>	test statistic $t\text{-bar}_{NT}$
<code>r(cv_10)</code>	exact 10% critical value for $t\text{-bar}_{NT}$
<code>r(cv_5)</code>	exact 5% critical value for $t\text{-bar}_{NT}$
<code>r(cv_1)</code>	exact 1% critical value for $t\text{-bar}_{NT}$
<code>r(zt)</code>	test statistic $Z_{t\text{-bar}}$
<code>r(ttildebar)</code>	test statistic $\tilde{t\text{-bar}}_{NT}$
<code>r(zttildebar)</code>	test statistic $\tilde{Z}_{t\text{-bar}}$
<code>r(p_zttildebar)</code>	p -value for $\tilde{Z}_{t\text{-bar}}$
<code>r(wtbar)</code>	test statistic $W_{t\text{-bar}}$
<code>r(p_wtbar)</code>	p -value for $W_{t\text{-bar}}$
<code>r(lags)</code>	lags used in ADF regressions
<code>r(lagm)</code>	average lags used in ADF regressions

Macros

<code>r(test)</code>	ips
<code>r(demean)</code>	demean , if the data were demeaned
<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(deterministics)</code>	constant or trend

`xtunitroot fisher` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(P)</code>	inverse χ^2 P statistic
<code>r(df_P)</code>	P statistic degrees of freedom
<code>r(p_P)</code>	p -value for P statistic
<code>r(L)</code>	inverse logit L statistic
<code>r(df_L)</code>	L statistic degrees of freedom
<code>r(p_L)</code>	p -value for L statistic
<code>r(Z)</code>	inverse normal Z statistic
<code>r(p_Z)</code>	p -value for Z statistic
<code>r(Pm)</code>	modified inverse χ^2 P_m statistic
<code>r(p_Pm)</code>	p -value for P_m statistic

Macros

<code>r(test)</code>	fisher
<code>r(urtest)</code>	dfuller or pperron
<code>r(options)</code>	options passed to dfuller or pperron
<code>r(demean)</code>	demean , if the data were demeaned

`xtunitroot hadri` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(var)</code>	variance of z under H_0
<code>r(mu)</code>	mean of z under H_0
<code>r(z)</code>	test statistic z
<code>r(p)</code>	p -value for z
<code>r(lags)</code>	lags used for HAC variance

Macros

<code>r(test)</code>	hadri
<code>r(demean)</code>	demean , if the data were demeaned
<code>r(robust)</code>	robust , if specified
<code>r(kernel)</code>	kernel used for HAC variance
<code>r(deterministics)</code>	constant or trend

Methods and formulas

Methods and formulas are presented under the following headings:

Levin–Lin–Chu test

Harris–Tsavalis test

Breitung test

Breitung test without trend

Breitung test with trend

Im–Pesaran–Shin test

Fisher-type tests

Hadri LM test

We consider a simple panel-data model with a first-order autoregressive component:

$$y_{it} = \rho_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it}$$

where $i = 1, \dots, N$ indexes panels and $t = 1, \dots, T$ indexes time. For the IPS, Fisher-type, and Hadri LM tests, we instead have $t = 1, \dots, T_i$, because they do not require balanced panels. ϵ_{it} is a zero-mean error term; we discuss the assumptions about ϵ_{it} for each test below. Here we use N to denote the number of panels, not the total number of observations. By default, $\mathbf{z}_{it} = 1$, so that the term $\mathbf{z}'_{it}\gamma_i$ represents panel-specific means (fixed effects). If `noconstant` is specified, $\mathbf{z}'_{it}\gamma_i$ vanishes. If `trend` is specified, $\mathbf{z}'_{it} = (1, t)$ so that $\mathbf{z}'_{it}\gamma_i$ represents panel-specific means and linear time trends.

Levin–Lin–Chu test

The starting point for the LLC test is the regression model

$$\Delta y_{it} = \phi y_{i,t-1} + \mathbf{z}'_{it}\gamma_i + \sum_{j=1}^{p_i} \theta_{ij} \Delta y_{i,t-j} + u_{it} \quad (7)$$

In (1'), LLC assume ϵ_{it} is independently distributed across panels and follows a stationary invertible process so that with sufficient lags of Δy_{it} included in (7), u_{it} will be white noise with potentially heterogeneous variance across panels. If `lags(#)` is specified with `xtunitroot llc`, then we set $p_i = \#$ for all panels $i = 1, \dots, N$. Otherwise, we fit (7) for each panel individually for lags $1 \dots p^{\max}$ and choose the lag length, p_i , that minimizes the information criterion requested by the user. During this step, we restrict estimation to the subset of observations that are valid when p^{\max} lags are included. Information criteria are defined as follows:

$$\begin{aligned} \text{AIC} &= (-2 \ln L + 2k)/M \\ \text{BIC} &= (-2 \ln L + k \ln M)/M \\ \text{HQIC} &= (-2 \ln L + 2k \ln \ln M)/M \end{aligned}$$

where $\ln L$ is the log likelihood assuming Gaussian errors, $M = T - p^{\max} - 2$, and k is the number of parameters in (7).

With the lag orders, p_i , in hand, the test proceeds in three main steps, the first of which is to use panel-by-panel OLS regressions to obtain the orthogonalized residuals

$$\hat{e}_{it} = \Delta y_{it} - \sum_{j=1}^{p_i} \hat{\theta}_{ij} \Delta y_{i,t-j} - \mathbf{z}'_{it} \hat{\gamma}_i \quad (8)$$

and

$$\hat{v}_{i,t-1} = y_{i,t-1} - \sum_{j=1}^{p_i} \tilde{\theta}_{ij} \Delta y_{i,t-j} - \mathbf{z}'_{it} \tilde{\gamma}_i \quad (9)$$

To control for panel-level heterogeneity, compute

$$\tilde{e}_{it} = \hat{e}_{it} / \hat{\sigma}_{\epsilon i} \quad \text{and} \quad \tilde{v}_{i,t-1} = \hat{v}_{i,t-1} / \hat{\sigma}_{\epsilon i}$$

where

$$\hat{\sigma}_{\epsilon i}^2 = \frac{1}{T - p_i - 1} \sum_{t=p_i}^T \left(\hat{e}_{it} - \hat{\delta}_i \hat{v}_{i,t-1} \right)^2$$

and $\hat{\delta}_i$ is the OLS coefficient from a regression of \hat{e}_{it} on $\hat{v}_{i,t-1}$. If time trends are included (by specifying the `trend` option), then a linear time trend is included in regressions (7), (8), and (9).

In the second step, we estimate the ratio of long-run to short-run variances. Under the null hypothesis of a unit root, the long-run variance of the model without panel-specific intercepts or time trends ($z_{it} = \{\emptyset\}$) can be estimated as

$$\hat{\sigma}_{yi}^2 = \frac{1}{T-1} \sum_{t=2}^T \Delta y_{it}^2 + \frac{2}{T-1} \sum_{j=1}^m K(j, m) \left(\sum_{t=j+2}^T \Delta y_{it} \Delta y_{i, t-j} \right)$$

where m is the maximum number of lags and $K(j, m)$ is the kernel weight function. Define $z = j/(m+1)$. If *kernel* is `bartlett`, then

$$K(j, m) = \begin{cases} 1 - z & 0 \leq z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kernel* is `parzen`, then

$$K(j, m) = \begin{cases} 1 - 6z^2 + 6z^3 & 0 \leq z \leq 0.5 \\ 2(1 - z)^3 & 0.5 < z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kernel* is `quadraticspectral`, then

$$K(j, m) = \begin{cases} 1 & z = 0 \\ 3\{\sin(\theta)/\theta - \cos(\theta)\}/\theta^2 & \text{otherwise} \end{cases}$$

where $\theta = 6\pi z/5$. If the user requests automatic bandwidth (lag) selection using the Newey–West algorithm, then we use the method documented in [Methods and formulas](#) of [R] `ivregress` with $\mathbf{z}_i = \mathbf{h} = 1$. If automatic lag selection with the LLC algorithm is chosen, then $m = \text{int}(3.21T^{1/3})$.

If panel-specific intercepts are included (by not specifying `noconstant`), then in the formula for $\hat{\sigma}_{yi}^2$ we replace Δy_{it} with $\Delta y_{it} - \overline{\Delta y_{it}}$, where $\overline{\Delta y_{it}}$ is the panel-level mean of Δy_{it} for panel i . Let $\hat{s}_i = \hat{\sigma}_{yi}/\hat{\sigma}_{\epsilon i}$, and denote $\hat{S}_N = N^{-1} \sum_i \hat{s}_i$.

In the third step, we run the OLS regression

$$\tilde{e}_{it} = \delta \tilde{v}_{i, t-1} + \tilde{\epsilon}_{it}$$

Called the “Basic test statistic” in the output of `xtunitroot llc` is the standard t statistic for δ computed as

$$t_\delta = \hat{\delta} / \text{se}_{(\hat{\delta})}$$

where

$$\text{se}_{(\hat{\delta})} = \hat{\sigma}_{\epsilon} \left(\sum_{i=1}^N \sum_{t=p_i+2}^T \tilde{v}_{i,t-1}^2 \right)^{-1/2}$$

$$\hat{\sigma}_{\epsilon}^2 = \frac{1}{N\tilde{T}} \sum_{i=1}^N \sum_{t=p_i+2}^T (\tilde{e}_{it} - \delta \tilde{v}_{i,t-1})^2$$

and $\tilde{T} = T - \bar{p} - 1$ with \bar{p} the average of p_1, \dots, p_N .

The adjusted test statistic is then computed as

$$t_{\delta}^* = \frac{t_{\delta} - N\tilde{T}\hat{S}_N \text{se}_{(\hat{\delta})} \mu_T^*}{\sigma_T^*}$$

where μ_T^* and σ_T^* are obtained by linearly interpolating the values in LLC (2002, table 2). t_{δ}^* is asymptotically $N(0, 1)$, with very negative values casting doubt on H_0 . If `noconstant` is specified, then the asymptotic properties hold as $\sqrt{N}/T \rightarrow \infty$. Otherwise, T must grow at a faster rate so that $N/T \rightarrow \infty$.

Harris–Tsavalis test

The starting point for the HT test is (4), where ϵ_{it} is assumed to be i.i.d. normal with constant variance across panels. Denote by $\hat{\rho}$ the least-squares estimate of ρ .

HT show that $\sqrt{N}(\hat{\rho} - \mu) \xrightarrow{D} N(0, \sigma^2)$ as $N \rightarrow \infty$ with T fixed, where μ and σ^2 depend on the specification of the deterministic component:

Option	μ	σ^2
<code>noconstant</code>	1	$\frac{2}{T(T-1)}$
<code>none</code>	$1 - \frac{3}{T+1}$	$\frac{3(17T^2 - 20T + 17)}{5(T-1)(T+1)^3}$
<code>trend</code>	$1 - \frac{15}{2(T+2)}$	$\frac{15(193T^2 - 728T + 1147)}{112(T+2)^3(T-2)}$

Breitung test

Suppose the data are generated by an AR(1) process so that we can express y_{it} as

$$y_{it} = \mathbf{z}_{it}' \boldsymbol{\gamma}_i + x_{it}$$

where

$$x_{it} = \alpha_1 x_{i,t-1} + \alpha_2 x_{i,t-2} + \epsilon_{it}$$

where ϵ_{it} is an error term. A prewhitening step is available to correct for serial correlation. The nonrobust version assumes that ϵ_{it} is uncorrelated across panels, whereas the robust version allows for the panels to be contemporaneously correlated with covariance matrix Ω .

Under the null hypothesis that y_{it} contains a unit root, that is, that y_{it} is difference stationary, $\alpha_1 + \alpha_2 = 1$. Under the alternative that y_{it} is stationary, $\alpha_1 + \alpha_2 < 1$. Some of the time indices and summation limits of the formulas below appear more complex than those in [Breitung \(2000\)](#) and [Breitung and Das \(2005\)](#) because our formulas make explicit the loss of observations because of the prewhitening step.

Breitung test without trend

Let $y_{i,t}^\ell = y_{i,t-1} - y_{i,p+1}$ unless `noconstant` is specified, in which case let $y_{i,t}^\ell = y_{i,t-1}$. If the `lags()` option is specified with `xtunitroot breitung`, then we replace Δy_{it} and $y_{i,t}^\ell$ in the following description with the residuals from running regressions of Δy_{it} and $y_{i,t}^\ell$ on $\Delta y_{i,t-1}, \dots, \Delta y_{i,t-p}$, where p is the lag order specified in `lags()`.

Define

$$\sigma_i^2 = \frac{1}{T-p-2} \sum_{t=p+2}^T (\Delta y_{it})^2$$

Then

$$\lambda = \frac{\sum_{i=1}^N \sum_{t=p+2}^T y_{it}^\ell \cdot \Delta y_{it} / \sigma_i^2}{\sqrt{\sum_{i=1}^N \sum_{t=p+2}^T (y_{it}^\ell)^2 / \sigma_i^2}}$$

λ is asymptotically distributed $N(0, 1)$ as $T \rightarrow \infty$ followed by $N \rightarrow \infty$; small values of λ cast doubt on H_0 .

For the robust version of the test statistic, let

$$\phi = \frac{\sum_{i=1}^N \sum_{t=p+2}^T y_{it}^\ell \cdot \Delta y_{it} / \sigma_i^2}{\sum_{i=1}^N \sum_{t=p+2}^T (y_{it}^\ell)^2 / \sigma_i^2}$$

and define $u_{it} = \Delta y_{it} - \phi y_{it}^\ell$. Let $\mathbf{u}_i = (u_{i,p+2}, \dots, u_{iT})'$ and let the $N \times N$ matrix $\mathbf{\Omega}$ have typical element $\mathbf{u}_i' \mathbf{u}_j / (T-p-2)$. Let $\mathbf{\Delta y}_t = (\Delta y_{1t}, \dots, \Delta y_{Nt})'$ and $\mathbf{y}_t^\ell = (y_{1,t-1}, \dots, y_{N,t-1})'$. Then

$$\lambda_{\text{robust}} = \frac{\sum_{t=p+2}^T (\mathbf{\Delta y}_t)' \mathbf{y}_t^\ell}{\sum_{t=p+2}^T (\mathbf{y}_t^\ell)' \mathbf{\Omega} \mathbf{y}_t^\ell}$$

For $\mathbf{\Omega}$ to be positive definite, we must have $T-p-1 \geq N$. As a practical matter, for $\mathbf{\Omega}$ to have good finite-sample properties, we need $T \gg N$. λ_{robust} is asymptotically distributed $N(0, 1)$ as $T \rightarrow \infty$ followed by $N \rightarrow \infty$; very negative values of λ_{robust} cast doubt on H_0 .

Breitung test with trend

Let p denote the number of lags requested in the `lags()` option. We fit the regression

$$\Delta y_{it} = \alpha_{i0} + \sum_{j=1}^p \alpha_{ij} \Delta y_{i,t-j} + \nu_{it}$$

and compute the $1 \times (T-p-1)$ vectors $\Delta \mathbf{u}_i$ and \mathbf{u}_i^ℓ with typical elements

$$\Delta u_{is} = \Delta y_{is} - \sum_{j=1}^p \hat{\alpha}_{ij} \Delta y_{i,s-j}$$

and

$$u_{is}^\ell = y_{i,s-1} - \sum_{j=1}^p \hat{\alpha}_{ij} y_{i,s-j-1}$$

for $s = 1, \dots, T - p - 1$. Let

$$\sigma_i^2 = \frac{1}{T - p - 2} \sum_{s=1}^{T-p-1} (\Delta u_{is} - \overline{\Delta u_i}) \Delta u_{is}$$

where $\overline{\Delta u_i}$ is the mean of Δu_{is} over s . Let $\Delta \mathbf{v}_i$ and \mathbf{v}_i^ℓ denote $1 \times (T - p - 1)$ vectors with typical elements

$$\Delta v_{is} = \sqrt{\frac{T - p - s - 1}{T - p - s}} \left(\Delta u_{is} - \frac{1}{T - p - s - 1} \sum_{j=s+1}^{T-p-1} \Delta u_{ij} \right)$$

and

$$v_{is}^\ell = u_{is}^\ell - u_{i1}^\ell - (T - p - 1) \overline{\Delta u_i}$$

Now

$$\lambda = \frac{\sum_{i=1}^N \sum_{s=1}^{T-p-1} v_{is}^\ell \Delta v_{is} / \sigma_i^2}{\sqrt{\sum_{i=1}^N \sum_{s=1}^{T-p-1} (v_{is}^\ell)^2 / \sigma_i^2}}$$

λ is asymptotically distributed $N(0, 1)$ as $T \rightarrow \infty$ followed by $N \rightarrow \infty$; very negative values of λ cast doubt on H_0 . The computation of the robust form of the statistic proceeds in a fashion entirely analogous to the case without trend.

Im–Pesaran–Shin test

Write the model as

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}_{it}' \boldsymbol{\gamma}_i + \epsilon_{it}$$

where ϵ_{it} is independently distributed normal for all i and t with panel-specific variance σ_i^2 . Denote $\Delta \mathbf{y}_i = (\Delta y_{i2}, \dots, \Delta y_{iT})'$ and $\mathbf{y}_{i,-1} = (y_{i1}, \dots, y_{i,T-1})'$. Note that to be consistent with the notation used in the rest of this documentation, we start the time index at $t = 1$ instead of $t = 0$ as in IPS (2003). Also let τ_T be a conformable vector of ones, $\mathbf{M}_\tau = \mathbf{I} - \tau_T (\tau_T' \tau_T)^{-1} \tau_T'$, $\mathbf{X}_i = (\tau_T, \mathbf{y}_{i,-1})$, and $\mathbf{M}_{X_i} = \mathbf{I} - \mathbf{X}_i (\mathbf{X}_i' \mathbf{X}_i)^{-1} \mathbf{X}_i'$.

First, we consider the case of no serial correlation, where the user does not specify the `lags()` option. Then

$$\tilde{t}\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N \tilde{t}_{iT}$$

where

$$\tilde{t}_{iT} = \frac{\Delta \mathbf{y}_i' \mathbf{M}_\tau \mathbf{y}_{i,-1}}{\tilde{\sigma}_{iT} (\mathbf{y}_{i,-1}' \mathbf{M}_\tau \mathbf{y}_{i,-1})^{1/2}}$$

and

$$\tilde{\sigma}_{iT}^2 = \frac{\Delta \mathbf{y}_i' \mathbf{M}_\tau \Delta \mathbf{y}_i}{T - 1}$$

Also

$$t\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N t_{iT}$$

where

$$t_{iT} = \frac{\Delta \mathbf{y}_i' \mathbf{M}_{\tau} \mathbf{y}_{i,-1}}{\hat{\sigma}_{iT} (\mathbf{y}_{i,-1}' \mathbf{M}_{\tau} \mathbf{y}_{i,-1})^{1/2}}$$

and

$$\tilde{\sigma}_{iT}^2 = \frac{\Delta \mathbf{y}_i' \mathbf{M}_{X_i} \Delta \mathbf{y}_i}{T-1}$$

Now

$$Z_{\tilde{t}\text{-bar}} = \frac{\sqrt{N} \left\{ \tilde{t}\text{-bar}_{NT} - N^{-1} \sum_{i=1}^N E(\tilde{t}_{T_i}) \right\}}{\sqrt{N^{-1} \sum_i \text{Var}(\tilde{t}_{T_i})}}$$

where $E(\tilde{t}_{T_i})$ and $\text{Var}(\tilde{t}_{T_i})$ are obtained by linearly interpolating the values shown in IPS (2003, table 1). $Z_{\tilde{t}\text{-bar}}$ has a standard normal limiting distribution for fixed T and $N \rightarrow \infty$; very negative values cast doubt on H_0 . Similarly,

$$Z_{t\text{-bar}} = \frac{\sqrt{N} \left\{ t\text{-bar}_{NT} - N^{-1} \sum_i E(t_{T_i}) \right\}}{\sqrt{N^{-1} \sum_i \text{Var}(t_{T_i})}}$$

If the `lags()` option is specified, then we fit the ADF regressions

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}_{it}' \boldsymbol{\gamma}_i + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{i,t-j} + \epsilon_i t$$

In matrix form, we can write this more compactly as

$$\Delta \mathbf{y}_i = \phi_i \mathbf{y}_{i,-1} + \mathbf{Q}_i \boldsymbol{\theta}_i + \epsilon_i$$

where $\mathbf{Q}_i = (\tau_t, \Delta \mathbf{y}_{i,-1}, \dots, \Delta \mathbf{y}_{i,-p_i})$ and $\boldsymbol{\theta}_i = (\alpha_i, \rho_{i1}, \dots, \rho_{ip_i})'$. Then

$$t\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N t_{iT}(p_i)$$

where

$$t_{iT}(p_i) = \frac{\sqrt{T-p_i-2} (\mathbf{y}_{i,-1}' \mathbf{M}_{Q_i} \Delta \mathbf{y}_i)}{(\mathbf{y}_{i,-1}' \mathbf{M}_{Q_i} \mathbf{y}_{i,-1})^{1/2} (\Delta \mathbf{y}_{i,-1}' \mathbf{M}_{Q_i} \Delta \mathbf{y}_{i,-1})^{1/2}}$$

where $\mathbf{M}_{Q_i} = \mathbf{I} - \mathbf{Q}_i (\mathbf{Q}_i' \mathbf{Q}_i)^{-1} \mathbf{Q}_i'$, $\mathbf{M}_{X_i} = \mathbf{I} - \mathbf{X}_i (\mathbf{X}_i' \mathbf{X}_i)^{-1} \mathbf{X}_i'$, and $\mathbf{X}_i = (\mathbf{y}_{i,-1}, \mathbf{Q}_i)$. Finally,

$$\mathbf{W}_{t\text{-bar}}(p) = \frac{\sqrt{N} \left[t\text{-bar}_{NT} - N^{-1} \sum_{i=1}^N E \{ t_{iT}(p_i) \} \right]}{\sqrt{N^{-1} \sum_{i=1}^N \text{Var} \{ t_{iT}(p_i) \}}}$$

where $E \{ t_{iT}(p_i) \}$ and $\text{Var} \{ t_{iT}(p_i) \}$ are obtained by linearly interpolating the values shown in IPS (2003, table 3). $\mathbf{W}_{t\text{-bar}}(p)$ has a standard normal limiting distribution as $T \rightarrow \infty$ followed by $N \rightarrow \infty$; very negative values cast doubt on H_0 .

Fisher-type tests

We use `dfuller` or `pperron` to perform unit-root tests on each panel; denote the p -value for the respective test on the i th panel as p_i . All of these tests are predicated on $T \rightarrow \infty$ so that the unit-root test for each panel is consistent. The P test is for finite N ; the other tests are valid whether N is finite or infinite. Then

$$P = -2 \sum_{i=1}^N \ln(p_i)$$

$P \sim \chi^2(2N)$ and large values cast doubt on H_0 .

$$Z = \frac{1}{\sqrt{N}} \sum_{i=1}^N \Phi^{-1}(p_i)$$

where $\Phi^{-1}()$ is the inverse of the standard normal cumulative distribution function. $Z \sim N(0, 1)$; very negative values of Z cast doubt on H_0 .

$$L = \sum_{i=1}^N \ln \left(\frac{p_i}{1 - p_i} \right)$$

$L^* = \sqrt{k}L \sim t(5N + 4)$ where

$$k = \frac{3(5N + 4)}{\pi^2 N(5N + 2)}$$

Very negative values of L^* cast doubt on H_0 . Finally,

$$P_m = -\frac{1}{\sqrt{N}} \sum_{i=1}^N \{\ln(p_i) + 1\}$$

$P_m \sim N(0, 1)$; very positive values of P_m cast doubt on H_0 .

Hadri LM test

As discussed in the main text, the Hadri LM test can be viewed as a test of $H_0: \sigma_u^2/\sigma_\epsilon^2 = 0$, where both u_{it} and ϵ_{it} are normally distributed random errors.

Let $\hat{\epsilon}_{it}$ denote the residuals from a regression of y_{it} on a panel-specific intercept or a panel-specific intercept and time trend if `trend` is specified. Then

$$\widehat{\text{LM}} = \frac{\frac{1}{N} \sum_i \frac{1}{T^2} \sum_t S_{it}^2}{\hat{\sigma}_\epsilon^2} \quad (10)$$

where

$$S_{it} = \sum_{j=1}^t \hat{\epsilon}_{ij}$$

and

$$\hat{\sigma}_\epsilon^2 = \frac{1}{NT'} \sum_{i=1}^N \sum_{t=1}^T \hat{\epsilon}_{it}^2$$

where $T' = T - 2$ if `trend` is specified and $T' = T - 1$ otherwise. Then

$$Z = \frac{\sqrt{N}(\widehat{\text{LM}} - \mu)}{\sigma}$$

where $\mu = 1/15$ and $\sigma = 11/6300$ if `trend` is specified and $\mu = 1/6$ and $\sigma = 1/45$ otherwise. $Z \sim N(0, 1)$ asymptotically as $T \rightarrow \infty$ followed by $N \rightarrow \infty$. Very positive values of Z cast doubt on H_0 . If `robust` is specified, then we instead use

$$\widehat{\text{LM}} = \frac{1}{N} \sum_{i=1}^N \left(\frac{\sum_{t=1}^T S_{it}^2}{T^2 \hat{\sigma}_{\epsilon,i}^2} \right)$$

where we calculate $\hat{\sigma}_{\epsilon,i}^2$ individually for each panel:

$$\hat{\sigma}_{\epsilon,i}^2 = \sum_{t=1}^T \hat{\epsilon}_{it}^2$$

If `kernel()` is specified, then we use (10) with

$$\hat{\sigma}_{\epsilon}^2 = \frac{1}{N} \sum_{i=1}^N \left\{ \frac{1}{T} \sum_{t=p+1}^T \hat{\epsilon}_{it}^2 + \frac{2}{T} \sum_{j=1}^m K(j, m) \sum_{t=j+1}^T \hat{\epsilon}_{it} \hat{\epsilon}_{i,t-j} \right\}$$

where m is the maximum number of lags and $K(\cdot, \cdot)$ is the kernel function defined previously.

Acknowledgments

We gratefully acknowledge users Fabian Bornhorst of the International Monetary Fund and Christopher F. Baum of the Department of Economics at Boston College and author of the Stata Press books [An Introduction to Modern Econometrics Using Stata](#) and [An Introduction to Stata Programming](#) for the `ipshin` and `levinlin` commands; Christopher Baum for the `hadrilm` command; and Scott Merryman of the Risk Management Agency for the `xtfisher` command. We also gratefully acknowledge Jörg Breitung of the Department of Economics at the Universität Bonn for useful discussions when implementing his tests. These contributions were beneficial during the development of `xtunitroot`.

References

Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.

Banerjee, A., M. Marcellino, and C. Osbat. 2005. Testing for PPP: Should we use panel methods? *Empirical Economics* 30: 77–91.

Breitung, J. 2000. The local power of some unit root tests for panel data. In *Advances in Econometrics, Volume 15: Nonstationary Panels, Panel Cointegration, and Dynamic Panels*, ed. B. H. Baltagi, 161–178. Amsterdam: JAI Press.

Breitung, J., and S. Das. 2005. Panel unit root tests under cross-sectional dependence. *Statistica Neerlandica* 59: 414–433.

Choi, I. 2001. Unit root tests for panel data. *Journal of International Money and Finance* 20: 249–272.

- Hadri, K. 2000. Testing for stationarity in heterogeneous panel data. *Econometrics Journal* 3: 148–161.
- Harris, R. D. F., and E. Tzavalis. 1999. Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of Econometrics* 91: 201–226.
- Heston, A., R. Summers, and B. Aten. 2006. Penn World Table Version 6.2. Center for International Comparisons of Production, Income, and Prices, University of Pennsylvania. http://pwt.econ.upenn.edu/php_site/pwt_index.php.
- Hlouskova, J., and M. Wagner. 2006. The performance of panel unit root and stationarity tests: Results from a large scale simulation study. *Econometric Reviews* 25: 85–116.
- Im, K. S., M. H. Pesaran, and Y. Shin. 2003. Testing for unit roots in heterogeneous panels. *Journal of Econometrics* 115: 53–74.
- Kwiatkowski, D., P. C. B. Phillips, P. Schmidt, and Y. Shin. 1992. Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of Econometrics* 54: 159–178.
- Levin, A., C.-F. Lin, and C.-S. J. Chu. 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics* 108: 1–24.
- Maddala, G. S., and S. Wu. 1999. A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics* 61: 631–652.
- Newey, W. K., and K. D. West. 1994. Automatic lag selection in covariance matrix estimation. *Review of Economic Studies* 61: 631–653.
- Nickell, S. J. 1981. Biases in dynamic models with fixed effects. *Econometrica* 49: 1417–1426.
- Obstfeld, M., and K. Rogoff. 1996. *Foundations of International Macroeconomics*. Cambridge, MA: MIT Press.
- O’Connell, P. G. J. 1998. The overvaluation of purchasing power parity. *Journal of International Economics* 44: 1–19.
- Oh, K.-Y. 1996. Purchasing power parity and unit root tests using panel data. *Journal of International Money and Finance* 15: 405–418.
- Patterson, K. 2000. *An Introduction to Applied Econometrics: A Time Series Approach*. Basingstoke, UK: Palgrave.
- Phillips, P. C. B., and H. R. Moon. 1999. Linear regression limit theory for nonstationary panel data. *Econometrica* 67: 1057–1111.
- . 2000. Nonstationary panel data analysis: An overview of some recent developments. *Econometric Reviews* 19: 263–286.
- Rogoff, K. 1996. The purchasing power parity puzzle. *Journal of Economic Literature* 34: 647–668.
- Whitehead, A. 2002. *Meta-Analysis of Controlled Clinical Trials*. Chichester, UK: Wiley.

Also see

- [TS] **dfgls** — DF-GLS unit-root test
- [TS] **dfuller** — Augmented Dickey–Fuller unit-root test
- [TS] **pperron** — Phillips–Perron unit-root test

Glossary

Arellano–Bond estimator. The Arellano–Bond estimator is a generalized method of moments (GMM) estimator for linear dynamic panel-data models that uses lagged levels of the endogenous variables as well as first differences of the exogenous variables as instruments. The Arellano–Bond estimator removes the panel-specific heterogeneity by first-differencing the regression equation.

autoregressive process. In autoregressive processes, the current value of a variable is a linear function of its own past values and a white-noise error term. For panel data, a first-order autoregressive process, denoted as an AR(1) process, is $y_{it} = \rho y_{i,t-1} + \epsilon_{it}$, where i denotes panels, t denotes time, and ϵ_{it} is white noise.

balanced data. A longitudinal or panel dataset is said to be balanced if each panel has the same number of observations. See also [weakly balanced](#) and [strongly balanced](#).

between estimator. The between estimator is a panel-data estimator that obtains its estimates by running OLS on the panel-level means of the variables. This estimator uses only the between-panel variation in the data to identify the parameters, ignoring any within-panel variation. For it to be consistent, the between estimator requires that the panel-level means of the regressors be uncorrelated with the panel-specific heterogeneity terms.

canonical link. Corresponding to each family of distributions in a generalized linear model is a canonical link function for which there is a sufficient statistic with the same dimension as the number of parameters in the linear predictor. The use of canonical link functions provides the GLM with desirable statistical properties, especially when the sample size is small.

conditional fixed-effects model. In general, including panel-specific dummies to control for fixed effects in nonlinear models results in inconsistent estimates. For some nonlinear models, the fixed-effect term can be removed from the likelihood function by conditioning on a sufficient statistic. For example, the conditional fixed-effect logit model conditions on the number of positive outcomes within each panel.

correlation structure. A correlation structure is a set of assumptions imposed on the within-panel variance–covariance matrix of the errors in a panel-data model. See [XT] [xtgee](#) for examples of different correlation structures.

cross-sectional data. Cross-sectional data refers to data collected over a set of individuals, such as households, firms, or countries sampled from a population at a given point in time.

cross-sectional time-series data. Cross-sectional time-series data is another name for panel data. The term *cross-sectional time-series data* is sometimes reserved for datasets in which a relatively small number of panels were observed over many periods. See also [panel data](#).

disturbance term. The disturbance term encompasses any shocks that occur to the dependent variable that cannot be explained by the conditional (or deterministic) portion of the model.

dynamic model. A dynamic model is one in which prior values of the dependent variable or disturbance term affect the current value of the dependent variable.

endogenous variable. An endogenous variable is a regressor that is correlated with the unobservable error term. Equivalently, an endogenous variable is one whose values are determined by the equilibrium or outcome of a structural model.

error-components model. The error-components model is another name for the random-effects model. See also [random-effects model](#).

exogenous variable. An exogenous variable is a regressor that is not correlated with any of the unobservable error terms in the model. Equivalently, an exogenous variable is one whose values change independently of the other variables in a structural model.

fixed-effects model. The fixed-effects model is a model for panel data in which the panel-specific errors are treated as fixed parameters. These parameters are panel-specific intercepts and therefore allow the conditional mean of the dependent variable to vary across panels. The linear fixed-effects estimator is consistent, even if the regressors are correlated with the fixed effects. See also [random-effects model](#).

generalized estimating equations (GEE). The method of generalized estimating equations is used to fit population-averaged panel-data models. GEE extends the GLM method by allowing the user to specify a variety of different within-panel correlation structures.

generalized linear model. The generalized linear model is an estimation framework in which the user specifies a distributional family for the dependent variable and a link function that relates the dependent variable to a linear combination of the regressors. The distribution must be a member of the exponential family of distributions. The generalized linear model encompasses many common models, including linear, probit, and Poisson regression.

idiosyncratic error term. In longitudinal or panel-data models, the idiosyncratic error term refers to the observation-specific zero-mean random-error term. It is analogous to the random-error term of cross-sectional regression analysis.

instrumental variables. Instrumental variables are exogenous variables that are correlated with one or more of the endogenous variables in a structural model. The term *instrumental variable* is often reserved for those exogenous variables that are not included as regressors in the model.

instrumental-variables (IV) estimator. An instrumental variables estimator uses instrumental variables to produce consistent parameter estimates in models that contain endogenous variables. IV estimators can also be used to control for measurement error.

interval data. Interval data are data in which the true value of the dependent variable is not observed. Instead, all that is known is that the value lies within a given interval.

link function. In a generalized linear model, the link function relates a linear combination of predictors to the expected value of the dependent variable. In a linear regression model, the link function is simply the identity function.

longitudinal data. Longitudinal data is another term for panel data. See also [panel data](#).

negative binomial regression model. The negative binomial regression model is for applications in which the dependent variable represents the number of times an event occurs. The negative binomial regression model is an alternative to the Poisson model for use when the dependent variable is overdispersed, meaning that the variance of the dependent variable is greater than its mean.

overidentifying restrictions. The order condition for model identification requires that the number of exogenous variables excluded from the model be at least as great as the number of endogenous regressors. When the number of excluded exogenous variables exceeds the number of endogenous regressors, the model is overidentified, and the validity of the instruments can then be checked via a test of overidentifying restrictions.

panel data. Panel data are data in which the same units were observed over multiple periods. The units, called panels, are often firms, households, or patients who were observed at several points in time. In a typical panel dataset, the number of panels is large, and the number of observations per panel is relatively small.

panel-corrected standard errors (PCSEs). The term *panel-corrected standard errors* refers to a class of estimators for the variance–covariance matrix of the OLS estimator when there are relatively few panels with many observations per panel. PCSEs account for heteroskedasticity, autocorrelation, or cross-sectional correlation.

Poisson regression model. The Poisson regression model is used when the dependent variable represents the number of times an event occurs. In the Poisson model, the variance of the dependent variable is equal to the conditional mean.

pooled estimator. A pooled estimator ignores the longitudinal or panel aspect of a dataset and treats the observations as if they were cross-sectional.

population-averaged model. A population-averaged model is used for panel data in which the parameters measure the effects of the regressors on the outcome for the average individual in the population. The panel-specific errors are treated as uncorrelated random variables drawn from a population with zero mean and constant variance, and the parameters measure the effects of the regressors on the dependent variable after integrating over the distribution of the random effects.

predetermined variable. A predetermined variable is a regressor in which its contemporaneous and future values are not correlated with the unobservable error term but past values are correlated with the error term.

prewhiten. To prewhiten is to apply a transformation to a time series so that it becomes white noise.

production function. A production function describes the maximum amount of a good that can be produced, given specified levels of the inputs.

quadrature. Quadrature is a set of numerical methods to evaluate a definite integral.

random-coefficients model. A random-coefficients model is a panel-data model in which group-specific heterogeneity is introduced by assuming that each group has its own parameter vector, which is drawn from a population common to all panels.

random-effects model. A random-effects model for panel data treats the panel-specific errors as uncorrelated random variables drawn from a population with zero mean and constant variance. The regressors must be uncorrelated with the random effects for the estimates to be consistent. See also *fixed-effects model*.

robust standard errors. Robust standard errors, also known as Huber/White or Taylor linearization standard errors, are based on the sandwich estimator of variance. Robust standard errors can be interpreted as representing the sample-to-sample variability of the parameter estimates, even when the model is misspecified. See also *semirobust standard errors*.

semirobust standard errors. Semirobust standard errors are closely related to robust standard errors and can be interpreted as representing the sample-to-sample variability of the parameter estimates, even when the model is misspecified, as long as the mean structure of the model is specified correctly. See also *robust standard errors*.

sequential limit theory. The sequential limit theory is a method of determining asymptotic properties of a panel-data statistic in which one index, say, N , the number of panels, is held fixed, while T , the number of time periods, goes to infinity, providing an intermediate limit. Then one obtains a final limit by studying the behavior of this intermediate limit as the other index (N here) goes to infinity.

strongly balanced. A longitudinal or panel dataset is said to be strongly balanced if each panel has the same number of observations, and the observations for different panels were all made at the same times.

unbalanced data. A longitudinal or panel dataset is said to be unbalanced if each panel does not have the same number of observations. See also *weakly balanced* and *strongly balanced*.

weakly balanced. A longitudinal or panel dataset is said to be weakly balanced if each panel has the same number of observations but the observations for different panels were not all made at the same times.

white noise. A variable u_t represents a white-noise process if the mean of u_t is zero, the variance of u_t is σ^2 , and the covariance between u_t and u_s is zero for all $s \neq t$.

within estimator. The within estimator is a panel-data estimator that removes the panel-specific heterogeneity by subtracting the panel-level means from each variable and then performing ordinary least squares on the demeaned data. The within estimator is used in fitting the linear fixed-effects model.

Subject and author index

This is the subject and author index for the *Longitudinal-Data/Panel-Data Reference Manual*. Readers interested in topics other than cross-sectional time-series should see the combined subject index (and the combined author index) in the *Glossary and Index*.

A

abond, estat subcommand, [XT] [xtabond](#)
[postestimation](#), [XT] [xtdpd](#) [postestimation](#),
[XT] [xtdpdsys](#) [postestimation](#)

Aigner, D. J., [XT] [xtfrontier](#)

Albert, P. S., [XT] [xtgee](#)

Allison, P. D., [XT] [xtlogit](#), [XT] [xtologit](#),
[XT] [xtprobit](#), [XT] [xtpoisson](#), [XT] [xtreg](#)

Alvarez, J., [XT] [xtabond](#)

Amemiya, T., [XT] [xhtaylor](#), [XT] [xtivreg](#)

Anderson, T. W., [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#), [XT] [xtivreg](#)

Andrews, M. J., [XT] [xtreg](#)

Arellano–Bond, [XT] [xtdpd](#), [XT] [xtdpdsys](#)
estimator, [XT] [xtabond](#), [XT] [Glossary](#)

Arellano–Bover estimator, [XT] [xtdpd](#), [XT] [xtdpdsys](#)

Arellano, M., [XT] [xtabond](#), [XT] [xtcloglog](#),
[XT] [xtdpd](#), [XT] [xtdpd](#) [postestimation](#),
[XT] [xtdpdsys](#), [XT] [xtdpdsys](#) [postestimation](#),
[XT] [xtivreg](#), [XT] [xtlogit](#), [XT] [xtologit](#),
[XT] [xtprobit](#), [XT] [xtpoisson](#), [XT] [xtprobit](#),
[XT] [xtreg](#)

Arora, S. S., [XT] [xtivreg](#), [XT] [xtreg](#)

Atella, V., [XT] [xtfrontier](#)

Aten, B., [XT] [xtunitroot](#)

autocorrelation,
dynamic model, [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#)
residual, [XT] [xtgee](#), [XT] [xtgls](#), [XT] [xtpcse](#),
[XT] [xtregar](#)
test, [XT] [xtabond](#), [XT] [xtabond](#) [postestimation](#),
[XT] [xtdpd](#) [postestimation](#), [XT] [xtdpdsys](#),
[XT] [xtdpdsys](#) [postestimation](#)

autoregressive process, [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#), [XT] [Glossary](#)

B

balanced data, [XT] [Glossary](#)

Balestra, P., [XT] [xtivreg](#)

Baltagi, B. H., [XT] [xt](#), [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#), [XT] [xhtaylor](#), [XT] [xhtaylor](#)
[postestimation](#), [XT] [xtivreg](#), [XT] [xtpoisson](#),
[XT] [xtprobit](#), [XT] [xtreg](#), [XT] [xtreg](#)
[postestimation](#), [XT] [xtregar](#), [XT] [xtunitroot](#)

Banerjee, A., [XT] [xtunitroot](#)

Battese–Coelli parameterization, [XT] [xtfrontier](#)

Battese, G. E., [XT] [xtfrontier](#)

Baum, C. F., [XT] [xtgls](#), [XT] [xtreg](#), [XT] [xtunitroot](#)

Beck, N. L., [XT] [xtgls](#), [XT] [xtpcse](#)

Bellocco, R., [XT] [xtgee](#)

Belotti, F., [XT] [xtfrontier](#)

Bera, A. K., [XT] [xtreg](#), [XT] [xtreg](#) [postestimation](#),
[XT] [xtregar](#)

between estimators, [XT] [xtivreg](#), [XT] [xtreg](#),
[XT] [Glossary](#)

between-cell means and variances, [XT] [xtdescribe](#),
[XT] [xtsum](#)

Bhargava, A., [XT] [xtregar](#)

binary outcome model, see outcomes, binary

Blackburne, E. F., III, [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#)

Blackwell, J. L., III, [XT] [xtgls](#), [XT] [xtpcse](#),
[XT] [xtreg](#)

Blundell–Bond estimator, [XT] [xtdpd](#), [XT] [xtdpdsys](#)

Blundell, R., [XT] [xtdpd](#), [XT] [xtdpdsys](#)

Bond, S., [XT] [xtabond](#), [XT] [xtdpd](#), [XT] [xtdpd](#)
[postestimation](#), [XT] [xtdpdsys](#), [XT] [xtdpdsys](#)
[postestimation](#), [XT] [xtivreg](#)

bootstrap standard errors, [XT] [vce_options](#)

Bornhorst, F., [XT] [xtunitroot](#)

Bottai, M., [XT] [xtreg](#)

Bover, O., [XT] [xtdpd](#), [XT] [xtdpdsys](#)

Brannon, B. R., [XT] [xtologit](#), [XT] [xtprobit](#)

Breitung, J., [XT] [xtunitroot](#)

Breitung test, [XT] [xtunitroot](#)

breitung, xtunitroot subcommand, [XT] [xtunitroot](#)

Breusch–Pagan Lagrange multiplier test, [XT] [xtreg](#)
[postestimation](#)

Breusch, T. S., [XT] [xtreg](#) [postestimation](#)

Bruno, G. S. F., [XT] [xtabond](#), [XT] [xtdpd](#),
[XT] [xtdpdsys](#), [XT] [xtreg](#)

C

Cameron, A. C., [XT] [xt](#), [XT] [xtnbreg](#),
[XT] [xtpoisson](#)

canonical link, [XT] [Glossary](#)

Caria, M. P., [XT] [xtgee](#)

Carter, S. L., [XT] [xt](#)

categorical outcomes, see outcomes, binary, see
outcomes, ordinal

Caudill, S. B., [XT] [xtfrontier](#)

Center for Human Resource Research, [XT] [xt](#)

Chang, Y.-J., [XT] [xtivreg](#), [XT] [xtreg](#)

Choi, I., [XT] [xtunitroot](#)

choice models, [XT] [xtgee](#), [XT] [xtlogit](#), [XT] [xtologit](#),
[XT] [xtprobit](#), [XT] [xtprobit](#)

Chu, C.-S. J., [XT] [xtunitroot](#)

cluster estimator of variance, [XT] [vce_options](#)
fixed-effects models,
linear, [XT] [xtreg](#)
Poisson, [XT] [xtpoisson](#)
linear dynamic panel-data models, [XT] [xtabond](#),
[XT] [xtdpd](#), [XT] [xtdpdsys](#)
population-averaged models, [XT] [xtgee](#)
complementary log-log, [XT] [xtcloglog](#)

cluster estimator of variance, population-averaged models, *continued*
 logit, [XT] [xtlogit](#)
 negative binomial, [XT] [xtnbreg](#)
 Poisson, [XT] [xtpoisson](#)
 probit, [XT] [xtprobit](#)
 random-effects models
 complementary log-log, [XT] [xtcloglog](#)
 linear, [XT] [xtreg](#)
 logistic, [XT] [xtlogit](#), [XT] [xtologit](#)
 Poisson, [XT] [xtpoisson](#)
 probit, [XT] [xtoprobit](#), [XT] [xtprobit](#)
 Coelli, T. J., [XT] [xtfrontier](#)
 complementary log-log regression, [XT] [xtcloglog](#), [XT] [xtgee](#)
 conditional
 fixed-effects model, [XT] [Glossary](#)
 logistic regression, [XT] [xtlogit](#), [XT] [xtologit](#)
 confidence interval
 for incidence-rate ratios, [XT] [xtgee](#), [XT] [xtnbreg](#), [XT] [xtpoisson](#)
 for odds ratios, [XT] [xtcloglog](#), [XT] [xtgee](#), [XT] [xtlogit](#), [XT] [xtologit](#)
 constrained estimation,
 fixed-effects models
 logit, [XT] [xtlogit](#)
 negative binomial, [XT] [xtnbreg](#)
 Poisson, [XT] [xtpoisson](#)
 random-effects models
 complementary log-log, [XT] [xtcloglog](#)
 interval-data regression, [XT] [xtintreg](#)
 logit, [XT] [xtlogit](#), [XT] [xtologit](#)
 negative binomial, [XT] [xtnbreg](#)
 Poisson, [XT] [xtpoisson](#)
 probit, [XT] [xtoprobit](#), [XT] [xtprobit](#)
 tobit, [XT] [xttobit](#)
 stochastic frontier models for panel data, [XT] [xtfrontier](#)
 Conway, M. R., [XT] [xtlogit](#), [XT] [xtologit](#), [XT] [xtoprobit](#), [XT] [xtprobit](#)
 correlated error, see robust, Huber/White/sandwich estimator of variance
 correlation structure, [XT] [xtcloglog](#), [XT] [xtgee](#), [XT] [xtgls](#), [XT] [xtlogit](#), [XT] [xtnbreg](#), [XT] [xtpcse](#), [XT] [xtpoisson](#), [XT] [xtprobit](#), [XT] [xtreg](#), [XT] [Glossary](#)
 cost frontier model, [XT] [xtfrontier](#)
 Cox, N. J., [XT] [xtdescribe](#)
 cross-sectional
 data, [XT] [Glossary](#)
 time-series data, [XT] [Glossary](#)
 Cui, J., [XT] [xtgee](#)
 Cummings, P., [XT] [xtpoisson](#)

D

Daidone, S., [XT] [xtfrontier](#)
 Das, S., [XT] [xtunitroot](#)

data,
 autocorrelated, see autocorrelation
 range of, see range of data
 summarizing, see summarizing data
 data manipulation, [XT] [xtset](#)
 Davidson, R., [XT] [xtgls](#), [XT] [xtpcse](#)
 De Hoyos, R. E., [XT] [xtreg](#)
 descriptive statistics, displaying, [XT] [xtsum](#), [XT] [xttab](#)
 dichotomous outcome model, see outcomes, binary
 DiNardo, J., [XT] [xtre](#)
 dispersion, measures of, [XT] [xtsum](#)
 disturbance term, [XT] [Glossary](#)
 Drukker, D. M., [XT] [xt](#), [XT] [xtregar](#)
 Dwyer, J. H., [XT] [xtreg](#)
 dynamic
 model, [XT] [Glossary](#)
 panel-data regression, [XT] [xtabond](#), [XT] [xtdpd](#), [XT] [xtdpdsys](#)

E

Eberhardt, M., [XT] [xtre](#)
 EGLS, see estimated generalized least squares
 endogenous
 covariates, [XT] [xtdpd](#), [XT] [xtdpdsys](#), [XT] [xthtaylor](#), [XT] [xtivreg](#)
 variable, [XT] [Glossary](#)
 error-components model, [XT] [xthtaylor](#), [XT] [Glossary](#)
 estat
 abond command, [XT] [xtabond postestimation](#), [XT] [xtdpd postestimation](#), [XT] [xtdpdsys postestimation](#)
 sargan command, [XT] [xtabond postestimation](#), [XT] [xtdpd postestimation](#), [XT] [xtdpdsys postestimation](#)
 wcorrelation command, [XT] [xtgee postestimation](#)
 estimated generalized least squares, [XT] [xtgls](#), [XT] [xtivreg](#), [XT] [xtreg](#)
 exogenous variable, [XT] [Glossary](#)

F

feasible generalized least squares, [XT] [xtgls](#), [XT] [xtivreg](#), [XT] [xtreg](#)
 Feinleib, M., [XT] [xtreg](#)
 FGLS, see feasible generalized least squares
 first-differenced estimator, [XT] [xtabond](#), [XT] [xtdpd](#), [XT] [xtdpdsys](#), [XT] [xtivreg](#)
 Fisher, M. R., [XT] [xtcloglog](#), [XT] [xtgee](#), [XT] [xtintreg](#), [XT] [xtlogit](#), [XT] [xtologit](#), [XT] [xtoprobit](#), [XT] [xtprobit](#), [XT] [xttobit](#)
 fisher, xtunitroot subcommand, [XT] [xtunitroot](#)
 Fisher-type test, [XT] [xtunitroot](#)

fixed-effects model, [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**, [XT] **xtivreg**, [XT] **xtlogit**,
 [XT] **xtnbreg**, [XT] **xtoprobit**, [XT] **xtpoisson**,
 [XT] **xtreg**, [XT] **xtregar**, [XT] **Glossary**

Flay, B. R., [XT] **xtologit**, [XT] **xtoprobit**

Ford, J. M., [XT] **xtfrontier**

Frank, M. W., [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**

Franzese, R. J., Jr., [XT] **xtpcse**

Franzini, L., [XT] **xtregar**

Frechette, G. R., [XT] **xtoprobit**

frequency table, [XT] **xtab**

frontier model, see **stochastic frontier model**

G

Galanti, M. R., [XT] **xtgee**

Gange, S. J., [XT] **xtcloglog**, [XT] **xtgee**,
 [XT] **xtintreg**, [XT] **xtlogit**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtprobit**, [XT] **xttobit**

Gavin, M. D., [XT] **xtologit**, [XT] **xtoprobit**

GEE, see **generalized estimating equations**

generalized

- estimating equations, [XT] **xtgee**, [XT] **Glossary**
- least squares,
 - estimated, see **estimated generalized least squares**
 - feasible, see **feasible generalized least squares**
- linear models, [XT] **xtgee**, [XT] **Glossary**
- method of moments, [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**

Gleason, L. R., [XT] **xtologit**, [XT] **xtoprobit**

GLM, see **generalized linear models**

Glowacz, K. M., [XT] **xtologit**, [XT] **xtoprobit**

GMM, see **generalized method of moments**

Goldstein, R., [XT] **xtreg**

Gould, W. W., [XT] **xtfrontier**

graphs, cross-sectional time-series data, [XT] **xtdata**,
 [XT] **xtline**

Greene, W. H., [XT] **xt**, [XT] **xtgls**, [XT] **xthtaylor**
postestimation, [XT] **xtpcse**, [XT] **xtpoisson**,
 [XT] **xtrc**, [XT] **xtreg**

Griffiths, W. E., [XT] **xtgls**, [XT] **xtpcse**, [XT] **xtrc**,
 [XT] **xtreg**

Griliches, Z., [XT] **xtgls**, [XT] **xtnbreg**, [XT] **xtpcse**,
 [XT] **xtpoisson**, [XT] **xtrc**

Gropper, D. M., [XT] **xtfrontier**

Grunfeld, Y., [XT] **xtgls**, [XT] **xtpcse**, [XT] **xtrc**

Guilkey, D. K., [XT] **xtprobit**

Guimarães, P., [XT] **xtnbreg**

Gutierrez, R. G., [XT] **xt**

H

Hadri, K., [XT] **xtunitroot**

Hadri Lagrange multiplier stationarity test,
 [XT] **xtunitroot**

hadri, **xtunitroot** subcommand, [XT] **xtunitroot**

Hall, B. H., [XT] **xtnbreg**, [XT] **xtpoisson**

Hansen, L. P., [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**

Hansen, W. B., [XT] **xtologit**, [XT] **xtoprobit**

Hardin, J. W., [XT] **xtgee**, [XT] **xtpoisson**

Harris, R. D. F., [XT] **xtunitroot**

Harris–Tzavalis test, [XT] **xtunitroot**

Hauck, W. W., [XT] **xtcloglog**, [XT] **xtlogit**,
 [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xtprobit**

Hausman, J. A., [XT] **xhtaylor**, [XT] **xtnbreg**,
 [XT] **xtpoisson**, [XT] **xtreg postestimation**

Hausman specification test, [XT] **xtreg postestimation**

Hausman–Taylor estimator, [XT] **xhtaylor**

Heston, A., [XT] **xtunitroot**

heteroskedasticity, [XT] **xtgls**

Hilbe, J. M., [XT] **xtgee**, [XT] **xtpoisson**

Hill, R. C., [XT] **xtgls**, [XT] **xtpcse**, [XT] **xtrc**,
 [XT] **xtreg**

Hlouskova, J., [XT] **xtunitroot**

Hoechle, D., [XT] **xtgls**, [XT] **xtpcse**, [XT] **xtreg**,
 [XT] **xtregar**

Holtz-Eakin, D., [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**

Honoré, B. E., [XT] **xttobit**

Horton, N. J., [XT] **xtgee**

Hosmer, D. W., Jr., [XT] **xtgee**

Hsiao, C., [XT] **xt**, [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**, [XT] **xtivreg**, [XT] **xtregar**

ht, **xtunitroot** subcommand, [XT] **xtunitroot**

Huber/White/sandwich estimator of variance, see **robust**,
 Huber/White/sandwich estimator of variance

I

idiosyncratic error term, [XT] **Glossary**

Ilardi, G., [XT] **xtfrontier**

Im, K. S., [XT] **xtunitroot**

Im–Pesaran–Shin test, [XT] **xtunitroot**

incidence-rate ratio, [XT] **xtgee**, [XT] **xtnbreg**,
 [XT] **xtpoisson**

instrumental-variables, [XT] **Glossary**

- estimator, [XT] **Glossary**
- regression, [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdpsys**, [XT] **xhtaylor**, [XT] **xtivreg**,
 [XT] **xtivreg postestimation**

interval data, [XT] **xtintreg**, [XT] **Glossary**

interval regression, random-effects, [XT] **xtintreg**

ips, **xtunitroot** subcommand, [XT] **xtunitroot**

IRR, see **incidence-rate ratio**

J

jackknife standard errors, [XT] **vce_options**

Johnson, C. A., [XT] **xtologit**, [XT] **xtoprobit**

Johnston, J., [XT] **xtrc**

Judge, G. G., [XT] **xtgls**, [XT] **xtpcse**, [XT] **xtrc**,
 [XT] **xtreg**

K

Kalbfleisch, J. D., [XT] [xtcloglog](#), [XT] [xtlogit](#),
 [XT] [xtologit](#), [XT] [xtoprobit](#), [XT] [xtprobit](#)
 Katz, J. N., [XT] [xtgls](#), [XT] [xtpcse](#)
 Khanti-Akom, S., [XT] [xthtaylor](#)
 Kiviet, J. F., [XT] [xtabond](#)
 Klein, M., [XT] [xtgee](#)
 Kleinbaum, D. G., [XT] [xtgee](#)
 Kmenta, J., [XT] [xtpcse](#)
 Kumbhakar, S. C., [XT] [xtfrontier](#)
 Kwiatkowski, D., [XT] [xtunitroot](#)

L

Lahiri, K., [XT] [xtgls](#)
 Layard, R., [XT] [xtabond](#), [XT] [xtdpd](#), [XT] [xtdpsys](#),
 [XT] [xtivreg](#)
 Lee, L. F., [XT] [xtreg](#)
 Lee, T.-C., [XT] [xtgls](#), [XT] [xtpcse](#), [XT] [xtcr](#),
 [XT] [xtreg](#)
 Lemeshow, S. A., [XT] [xtgee](#)
 Leonard, M., [XT] [xtgee](#)
 Levin, A., [XT] [xtunitroot](#)
 Levin–Lin–Chu test, [XT] [xtunitroot](#)
 Li, Q., [XT] [xtivreg](#), [XT] [xtreg](#) [postestimation](#),
 [XT] [xtregar](#)
 Liang, K.-Y., [XT] [xtcloglog](#), [XT] [xtgee](#), [XT] [xtlogit](#),
 [XT] [xtnbreg](#), [XT] [xtologit](#), [XT] [xtoprobit](#),
 [XT] [xtpoisson](#), [XT] [xtprobit](#)
 Libois, F., [XT] [xtreg](#)
 limited dependent variables, [XT] [xtcloglog](#), [XT] [xtgee](#),
 [XT] [xtlogit](#), [XT] [xtnbreg](#), [XT] [xtologit](#),
 [XT] [xtoprobit](#), [XT] [xtpoisson](#), [XT] [xtprobit](#)
 Lin, C.-F., [XT] [xtunitroot](#)
 Lindstrom, M. J., [XT] [xtcloglog](#), [XT] [xtgee](#),
 [XT] [xtintreg](#), [XT] [xtlogit](#), [XT] [xtologit](#),
 [XT] [xtoprobit](#), [XT] [xtprobit](#), [XT] [xttobit](#)
 linear regression, [XT] [xtabond](#), [XT] [xtdpd](#),
 [XT] [xtdpsys](#), [XT] [xtfrontier](#), [XT] [xtgee](#),
 [XT] [xtgls](#), [XT] [xthtaylor](#), [XT] [xtintreg](#),
 [XT] [xtivreg](#), [XT] [xtpcse](#), [XT] [xtcr](#),
 [XT] [xtreg](#), [XT] [xtregar](#), [XT] [xttobit](#)
 link function, [XT] [xtgee](#), [XT] [Glossary](#)
 llc, [xtunitroot](#) subcommand, [XT] [xtunitroot](#)
 Lockwood, J. R., [XT] [xtreg](#)
 logistic and logit regression,
 fixed-effects, [XT] [xtlogit](#)
 generalized estimating equations, [XT] [xtgee](#)
 population-averaged, [XT] [xtgee](#), [XT] [xtlogit](#)
 random-effects, [XT] [xtlogit](#), [XT] [xtologit](#)
 longitudinal data, [XT] [Glossary](#)
 Lovell, C. A. K., [XT] [xtfrontier](#)
 Lütkepohl, H., [XT] [xtgls](#), [XT] [xtpcse](#), [XT] [xtcr](#),
 [XT] [xtreg](#)

M

MacKinnon, J. G., [XT] [xtgls](#), [XT] [xtpcse](#)
 MaCurdy, T. E., [XT] [xthtaylor](#)
 Maddala, G. S., [XT] [xtgls](#), [XT] [xtunitroot](#)
 Marcellino, M., [XT] [xtunitroot](#)
 McCaffrey, D. F., [XT] [xtreg](#)
 McCullagh, P., [XT] [vce_options](#), [XT] [xtgee](#),
 [XT] [xtpoisson](#)
 means, displaying, [XT] [xtsum](#)
 Meeusen, W., [XT] [xtfrontier](#)
 Merryman, S., [XT] [xtunitroot](#)
 Mihaly, K., [XT] [xtreg](#)
 model specification test, see [specification test](#)
 Molenberghs, G., [XT] [xtreg](#) [postestimation](#)
 Moon, H. R., [XT] [xtunitroot](#)
 Mundlak, Y., [XT] [xtivreg](#), [XT] [xtregar](#)
 Murphy, J. L., [XT] [xtprobit](#)

N

Narendranathan, W., [XT] [xtregar](#)
 Naylor, J. C., [XT] [xtcloglog](#), [XT] [xtintreg](#),
 [XT] [xtlogit](#), [XT] [xtologit](#), [XT] [xtoprobit](#),
 [XT] [xtpoisson](#), [XT] [xtprobit](#), [XT] [xttobit](#)
 negative binomial regression, [XT] [Glossary](#)
 fixed-effects, [XT] [xtnbreg](#)
 population-averaged, [XT] [xtgee](#), [XT] [xtnbreg](#)
 random-effects, [XT] [xtnbreg](#)
 Nelder, J. A., [XT] [vce_options](#), [XT] [xtgee](#),
 [XT] [xtpoisson](#)
 Neuhaus, J. M., [XT] [xtcloglog](#), [XT] [xtintreg](#),
 [XT] [xtlogit](#), [XT] [xtologit](#), [XT] [xtoprobit](#),
 [XT] [xtprobit](#)
 Newey, W. K., [XT] [xtabond](#), [XT] [xtdpd](#),
 [XT] [xtdpsys](#), [XT] [xtunitroot](#)
 Newton, H. J., [XT] [xtgee](#)
 Newton, M. A., [XT] [xtcloglog](#), [XT] [xtgee](#),
 [XT] [xtintreg](#), [XT] [xtlogit](#), [XT] [xtologit](#),
 [XT] [xtoprobit](#), [XT] [xtprobit](#), [XT] [xttobit](#)
 Nichols, A., [XT] [xtcr](#), [XT] [xtreg](#)
 Nickell, S. J., [XT] [xtabond](#), [XT] [xtdpd](#),
 [XT] [xtdpsys](#), [XT] [xtivreg](#), [XT] [xtunitroot](#)

O

O'Connell, P. G. J., [XT] [xtunitroot](#)
 O'Donnell, C. J., [XT] [xtfrontier](#)
 observed information matrix, [XT] [vce_options](#)
 Obstfeld, M., [XT] [xtunitroot](#)
 odds ratio, [XT] [xtcloglog](#), [XT] [xtgee](#), [XT] [xtlogit](#),
 [XT] [xtologit](#)
 Oh, K.-Y., [XT] [xtunitroot](#)
 OIM, see [observed information matrix](#)
 OPG, see [outer product of the gradient](#)
 ordinal outcome model, see [outcomes](#), [ordinal](#)
 Orsini, N., [XT] [xtreg](#)
 Osbat, C., [XT] [xtunitroot](#)

outcomes,
 binary,
 complementary log-log, [XT] **xtcloglog**
 generalized estimating equations, [XT] **xtgee**
 logistic, [XT] **xtlogit**
 probit, [XT] **xtprobit**
 count,
 generalized estimating equations, [XT] **xtgee**
 negative binomial, [XT] **xtnbreg**
 Poisson, [XT] **xtpoisson**
 ordinal,
 logistic, [XT] **xtologit**
 probit, [XT] **xtoprobit**
 outer product of the gradient, [XT] **vce_options**
 Over, M., [XT] **xtivreg**
 overidentifying restrictions, [XT] **Glossary**
 tests of, [XT] **xtabond**, [XT] **xtabond**
 postestimation, [XT] **xtdpd**, [XT] **xtdpdsys**,
 [XT] **xtdpdsys postestimation**

P

Pagan, A. R., [XT] **xreg postestimation**
 Palta, M., [XT] **xtcloglog**, [XT] **xtgee**, [XT] **xtintreg**,
 [XT] **xtlogit**, [XT] **xtologit**, [XT] **xtoprobit**,
 [XT] **xtprobit**, [XT] **xttobit**
 panel data, [XT] **Glossary**
 panel-corrected standard error, [XT] **xtpcse**,
 [XT] **Glossary**
 panels, variable identifying, [XT] **xtset**
 Patterson, K., [XT] **xtunitroot**
 PCSE, see panel-corrected standard error
 Pendergast, J. F., [XT] **xtcloglog**, [XT] **xtgee**,
 [XT] **xtintreg**, [XT] **xtlogit**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtprobit**, [XT] **xttobit**

Pesaran, M. H., [XT] **xtunitroot**
 Phillips, P. C. B., [XT] **xtunitroot**
 Pickles, A., [XT] **xtgee**, [XT] **xreg**
 Pitblado, J. S., [XT] **xtfrontier**
 Poi, B. P., [XT] **xtfrontier**, [XT] **xtrc**
 Poisson regression
 fixed-effects, [XT] **xtpoisson**
 model, [XT] **Glossary**
 population-averaged, [XT] **xtgee**, [XT] **xtpoisson**
 random-effects, [XT] **xtpoisson**
 pooled estimator, [XT] **Glossary**
 population-averaged model, [XT] **xtcloglog**, [XT] **xtgee**,
 [XT] **xtlogit**, [XT] **xtnbreg**, [XT] **xtpoisson**,
 [XT] **xtprobit**, [XT] **xreg**, [XT] **Glossary**
 Prais–Winsten regression, [XT] **xtpcse**
 predetermined variable, [XT] **Glossary**
 Prentice, R. L., [XT] **xtgee**
 prewhiten, [XT] **Glossary**
 probit regression,
 generalized estimating equations, [XT] **xtgee**
 population-averaged, [XT] **xtgee**, [XT] **xtprobit**
 random-effects, [XT] **xtoprobit**, [XT] **xtprobit**

production
 frontier model, [XT] **xtfrontier**
 function, [XT] **Glossary**

Q

Qaqish, B., [XT] **xtgee**
 quadchk command, [XT] **quadchk**
 quadrature, [XT] **Glossary**
 Gauss–Hermite, [XT] **quadchk**
 qualitative dependent variables, [XT] **xtcloglog**,
 [XT] **xtgee**, [XT] **xtlogit**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtprobit**

R

Rabe-Hesketh, S., [XT] **xtcloglog**, [XT] **xtgee**,
 [XT] **xtintreg**, [XT] **xtlogit**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**,
 [XT] **xreg**, [XT] **xttobit**
 random-coefficients
 linear regression, [XT] **xtrc**
 model, [XT] **Glossary**
 random-effects model, [XT] **xtabond**, [XT] **xtcloglog**,
 [XT] **xtdpd**, [XT] **xtdpdsys**, [XT] **xtgee**,
 [XT] **xhtaylor**, [XT] **xtintreg**, [XT] **xtivreg**,
 [XT] **xtlogit**, [XT] **xtnbreg**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**,
 [XT] **xreg**, [XT] **xregar**, [XT] **xttobit**,
 [XT] **Glossary**
 range of data, [XT] **xtsum**
 Rao, D. S. P., [XT] **xtfrontier**
 Ratcliffe, S. J., [XT] **xtgee**
 regression (in generic sense),
 dummy variables, with, [XT] **xreg**
 fixed-effects, [XT] **xreg**
 instrumental variables, [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdsys**, [XT] **xhtaylor**, [XT] **xtivreg**
 random-effects, [XT] **xtgee**, [XT] **xreg**
 Revankar, N. S., [XT] **xtfrontier**
 robust standard errors, [XT] **Glossary**
 robust, Huber/White/sandwich estimator of variance,
 [XT] **vce_options**
 fixed-effects models,
 linear, [XT] **xreg**
 Poisson, [XT] **xtpoisson**
 linear dynamic panel-data estimation, [XT] **xtabond**,
 [XT] **xtdpd**, [XT] **xtdpdsys**
 population-averaged models, [XT] **xtgee**
 complementary log-log, [XT] **xtcloglog**
 logit, [XT] **xtlogit**
 negative binomial, [XT] **xtnbreg**
 Poisson, [XT] **xtpoisson**
 probit, [XT] **xtprobit**
 random-effects model
 complementary log-log, [XT] **xtcloglog**
 linear, [XT] **xreg**
 logistic, [XT] **xtlogit**, [XT] **xtologit**

robust, Huber/White/sandwich estimator of variance, random-effects model, *continued*
 Poisson, [XT] **xtpoisson**
 probit, [XT] **xtprobit**, [XT] **xtprobit**
 Rogoff, K., [XT] **xtunitroot**
 Roodman, D., [XT] **xtddpd**, [XT] **xtddpsys**
 Rosen, H. S., [XT] **xtabond**, [XT] **xtddpd**, [XT] **xtddpsys**

S

sandwich/Huber/White estimator of variance, see **robust**, Huber/White/sandwich estimator of variance
 Sarafidis, V., [XT] **xreg**
 sargan, estat subcommand, [XT] **xtabond** **postestimation**, [XT] **xtddpd** **postestimation**, [XT] **xtddpsys** **postestimation**
 Sargan test, [XT] **xtabond** **postestimation**, [XT] **xtddpd** **postestimation**, [XT] **xtddpsys** **postestimation**
 Sass, T. R., [XT] **xreg**
 Schank, T., [XT] **xreg**
 Schmidt, P., [XT] **xtfrontier**, [XT] **xtunitroot**
 Schunck, R., [XT] **xreg**
 semirobust standard errors, [XT] **Glossary**
 sequential limit theory, [XT] **Glossary**
 Shin, Y., [XT] **xtunitroot**
 Shults, J., [XT] **xtgee**
 Skrondal, A., [XT] **xtcloglog**, [XT] **xtgee**, [XT] **xtintreg**, [XT] **xtlogit**, [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**, [XT] **xttobit**
 Smith, A. F. M., [XT] **xtcloglog**, [XT] **xtintreg**, [XT] **xtlogit**, [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**, [XT] **xttobit**
 Sobol, D. F., [XT] **xtologit**, [XT] **xtoprobit**
 Sosa-Escudero, W., [XT] **xreg**, [XT] **xreg** **postestimation**, [XT] **xtregar**
 specification test, [XT] **xreg** **postestimation**
 Spiegel, D. C., [XT] **xtologit**, [XT] **xtoprobit**
 standard deviations, displaying, [XT] **xtsum**
 standard errors,
 bootstrap, see bootstrap standard errors
 jackknife, see jackknife standard errors
 panel-corrected, see panel-corrected standard error
 robust, see **robust**, Huber/White/sandwich estimator of variance
 semirobust, see semirobust standard errors
 Stewart, M. B., [XT] **xtprobit**
 stochastic frontier model, [XT] **xtfrontier**
 Stock, J. H., [XT] **xtcloglog**, [XT] **xhtaylor**, [XT] **xtlogit**, [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**, [XT] **xreg**
 strongly balanced, [XT] **Glossary**
 Sturdivant, R. X., [XT] **xtgee**
 summarizing data, [XT] **xtsum**
 Summers, R., [XT] **xtunitroot**
 Sussman, S., [XT] **xtologit**, [XT] **xtoprobit**
 Swamy, P. A. V. B., [XT] **xtivreg**, [XT] **xtrec**, [XT] **xreg**

T

table, frequency, see frequency table
 Taub, A. J., [XT] **xreg**
 Taylor, C., [XT] **xtgee**, [XT] **xreg**
 Taylor, W. E., [XT] **xhtaylor**
 test,
 autocorrelation, see autocorrelation test
 Breitung, see Breitung test
 Breusch–Pagan Lagrange multiplier, see Breusch–Pagan Lagrange multiplier test
 test, *continued*
 Fisher-type, see Fisher-type test
 Hadri Lagrange multiplier, see Hadri Lagrange multiplier stationarity test
 Harris–Tzavalis, see Harris–Tzavalis test
 Hausman specification, see Hausman specification test
 Im–Pesaran–Shin, see Im–Pesaran–Shin test
 Levin–Lin–Chu, see Levin–Lin–Chu test
 model specification, see specification test
 overidentifying restrictions, see overidentifying restrictions, tests of
 quadrature, see quadrature
 unit-root, see unit-root test
 tobit regression, random-effects, [XT] **xttobit**
 Trivedi, P. K., [XT] **xt**, [XT] **xtnbreg**, [XT] **xtpoisson**
 Twisk, J. W. R., [XT] **xtgee**, [XT] **xtlogit**, [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xreg**
 two-stage least squares, [XT] **xhtaylor**, [XT] **xtivreg**
 Tzavalis, E., [XT] **xtunitroot**

U

Ulene, A. L., [XT] **xtologit**, [XT] **xtoprobit**
 unbalanced data, [XT] **Glossary**
 unit-root test, [XT] **xtunitroot**
 Upward, R., [XT] **xreg**
 Ureta, M., [XT] **xreg**

V

van den Broeck, J., [XT] **xtfrontier**
 Varadharajan-Krishnakumar, J., [XT] **xtivreg**
 variable identifying panels, [XT] **xtset**
 variance,
 displaying, [XT] **xtsum**
 estimators, [XT] **vce_options**
 Huber/White/sandwich estimator, see **robust**, Huber/White/sandwich estimator of variance
 vce() option, [XT] **vce_options**
 Verardi, V., [XT] **xreg**
 Verbeke, G., [XT] **xreg** **postestimation**

W

Wagner, M., [XT] **xtunitroot**
 Watson, M. W., [XT] **xtcloglog**, [XT] **xtlogit**,
 [XT] **xtologit**, [XT] **xtoprobit**, [XT] **xtpoisson**,
 [XT] **xtprobit**, [XT] **xtreg**
 wcorrelation, estat subcommand, [XT] **xtgee**
postestimation
 weakly balanced, [XT] **Glossary**
 Wedderburn, R. W. M., [XT] **xtgee**
 West, K. D., [XT] **xtunitroot**
 White, H. L., Jr., [XT] **xtivreg**
 white noise, [XT] **Glossary**
 White/Huber/sandwich estimator of variance, see **robust**,
 Huber/White/sandwich estimator of variance
 Whitehead, A., [XT] **xtunitroot**
 Whitney-Saltiel, D. A., [XT] **xtologit**, [XT] **xtoprobit**
 Windmeijer, F., [XT] **xtabond**, [XT] **xtdpd**,
 [XT] **xtdpdsys**
 within estimators, [XT] **xhtaylor**, [XT] **xtivreg**,
 [XT] **xtreg**, [XT] **xtregar**, [XT] **Glossary**
 within-cell means and variances, [XT] **xtsum**
 Wooldridge, J. M., [XT] **xt**, [XT] **xtcloglog**,
 [XT] **xtivreg**, [XT] **xtlogit**, [XT] **xtologit**,
 [XT] **xtoprobit**, [XT] **xtpoisson**, [XT] **xtprobit**,
 [XT] **xtreg**
 Wright, J. H., [XT] **xhtaylor**
 Wu, P. X., [XT] **xtregar**
 Wu, S., [XT] **xtunitroot**

X

xtabond command, [XT] **xtabond**, [XT] **xtabond**
postestimation
xtcloglog command, [XT] **quadchk**, [XT] **xtcloglog**,
 [XT] **xtcloglog postestimation**
xtdata command, [XT] **xtdata**
xtdescribe command, [XT] **xtdescribe**
xtdpd command, [XT] **xtdpd**, [XT] **xtdpd**
postestimation
xtdpdsys command, [XT] **xtdpdsys**, [XT] **xtdpdsys**
postestimation
xtfrontier command, [XT] **xtfrontier**,
 [XT] **xtfrontier postestimation**
xtgee command, [XT] **xtgee**, [XT] **xtgee**
postestimation
xtgls command, [XT] **xtgls**, [XT] **xtgls postestimation**
xhtaylor command, [XT] **xhtaylor**, [XT] **xhtaylor**
postestimation
xtintreg command, [XT] **quadchk**, [XT] **xtintreg**,
 [XT] **xtintreg postestimation**
xtivreg command, [XT] **xtivreg**, [XT] **xtivreg**
postestimation
xtline command, [XT] **xtline**
xtlogit command, [XT] **quadchk**, [XT] **xtlogit**,
 [XT] **xtlogit postestimation**
xtnbreg command, [XT] **xtnbreg**, [XT] **xtnbreg**
postestimation
xtologit command, [XT] **xtologit**, [XT] **xtologit**
postestimation

xtoprobit command, [XT] **xtoprobit**, [XT] **xtoprobit**
postestimation
xtpcse command, [XT] **xtpcse**, [XT] **xtpcse**
postestimation
xtpoisson command, [XT] **quadchk**, [XT] **xtpoisson**,
 [XT] **xtpoisson postestimation**
xtprobit command, [XT] **quadchk**, [XT] **xtprobit**,
 [XT] **xtprobit postestimation**
xtrc command, [XT] **xtrc**, [XT] **xtrc postestimation**
xtreg command, [XT] **xtreg**, [XT] **xtreg**
postestimation
xtregar command, [XT] **xtregar**, [XT] **xtregar**
postestimation
xtset command, [XT] **xtset**
xtsum command, [XT] **xtsum**
xttab command, [XT] **xttab**
xttest0 command, [XT] **xtreg postestimation**
xttobit command, [XT] **quadchk**, [XT] **xttobit**,
 [XT] **xttobit postestimation**
xttrans command, [XT] **xttab**
xtunitroot
 breitung command, [XT] **xtunitroot**
 fisher command, [XT] **xtunitroot**
 hadri command, [XT] **xtunitroot**
 ht command, [XT] **xtunitroot**
 ips command, [XT] **xtunitroot**
 llc command, [XT] **xtunitroot**

Y

Yogo, M., [XT] **xhtaylor**

Z

Zeger, S. L., [XT] **xtcloglog**, [XT] **xtgee**, [XT] **xtlogit**,
 [XT] **xtnbreg**, [XT] **xtologit**, [XT] **xtoprobit**,
 [XT] **xtpoisson**, [XT] **xtprobit**
 Zellner, A., [XT] **xtfrontier**
 Zhao, L. P., [XT] **xtgee**

