

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

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## 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 `ec2s1s` 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 \(1981\)](#).

## Quick start

Random-effects linear panel-data model with outcome `y`, exogenous `x1`, and `x2` instrumented by `x3` using `xtset` data

```
xtivreg y x1 (x2 = x3)
```

Use fixed-effects estimator and include [indicators](#) for each level of categorical variable `a`

```
xtivreg y x1 i.a (x2 = x3), fe
```

Use between-effects estimator and include [indicators](#) for levels of `b` as instruments

```
xtivreg y x1 i.a (x2 = x3 i.b), be
```

First-differenced model of `y` as a function of `x1` and `x2` and the lag of `y` instrumented by its third lag

```
xtivreg y x1 x2 (L.y = L3.y), fd
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Instrumental-variables regression (FE, RE, BE, FD)

## 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

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Model

<code>re</code>	use random-effects estimator; the default
<code>ec2sls</code>	use Baltagi's EC2SLS random-effects estimator
<code>nosa</code>	use the Baltagi–Chang estimators of the variance components
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables

SE/Robust

<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>robust</code> , <code>cluster <i>clustvar</i></code> , <code>bootstrap</code> , or <code>jackknife</code>
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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 $\chi^2$ statistics
<code>theta</code>	report $\theta$
<code>display_options</code>	control columns and 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

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<i>BE_options</i>	Description
Model	
<code>be</code>	use between-effects estimator
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables
SE/Robust	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be conventional, <code>robust</code> , <code>cluster clustvar</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 $\chi^2$ statistics
<code>display_options</code>	control columns and 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

<i>FE_options</i>	Description
Model	
<code>fe</code>	use fixed-effects estimator
<code>regress</code>	treat covariates as exogenous and ignore instrumental variables
SE/Robust	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be conventional, <code>robust</code> , <code>cluster clustvar</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 $\chi^2$ statistics
<code>display_options</code>	control columns and 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

<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/Robust	
<code>vce(<i>vcetype</i>)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>robust</code> , <code>cluster <i>clustvar</i></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 $\chi^2$ statistics
<code>display_options</code>	control columns and 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 `varlistiv` may contain factor variables, except for the `fd` estimator; see [U] 11.4.3 **Factor variables**. `devar`, `varlist1`, `varlist2`, and `varlistiv` may contain time-series operators; see [U] 11.4.4 **Time-series varlists**. `by`, `collect`, 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.

## 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 `devar` on `varlist1` and `varlist2`, ignoring `varlistiv`.

### 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, re* in *Methods and formulas of [XT] xtreg*.

## 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  $\chi^2$  statistics.

`theta` specifies that the output include the estimated value of  $\theta$  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*: `noci`, `nopvalues`, `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 BE model

## Model

`be` requests the between regression estimator.

`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 *depar* on *varlist*<sub>1</sub> and *varlist*<sub>2</sub>, ignoring *varlist*<sub>v</sub>.

## 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 clustervar`), 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 of [XT] xtreg*.

## 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  $\chi^2$  statistics.

*display\_options*: `noci`, `nopvalues`, `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 be treated as exogenous and that the instrument list be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of *devar* on *varlist*<sub>1</sub> and *varlist*<sub>2</sub>, ignoring *varlist*<sub>iv</sub>.

### 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](#), [fe](#) in *Methods and formulas* of [XT] [xtreg](#).

### 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*<sup>2</sup> statistics be reported instead of  $\chi^2$  statistics.

*display\_options*: `nocl`, `nopvalues`, `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 be treated as exogenous and that the instrument list be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of *devar* on *varlist*<sub>1</sub> and *varlist*<sub>2</sub>, ignoring *varlist*<sub>iv</sub>.

## 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](#), *fe* in *Methods and formulas* of [XT] [xtreg](#).

## 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  $\chi^2$  statistics.

`display_options`: `noc1`, `nopvalues`, `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

[stata.com](http://www.stata.com)

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  $\nu_{it}$ ;

$\mathbf{X}_{1it}$  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,  $N = \sum_{i=1}^n T_i$ .

`xtivreg` offers five different estimators, which may be applied to models having the form of (1). The first-differenced estimator (FD2SLS) removes the  $\mu_i$  by fitting the model in first differences. The within estimator (FE2SLS) fits the model after sweeping out the  $\mu_i$  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  $\mu_i$  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  $\mu_i$ , all the estimators assume that the idiosyncratic error term  $\nu_{it}$  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  $\mu_i$ . If they are assumed to be fixed, the  $\mu_i$  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  $\mu_i$  are assumed to be random, they are also assumed to be i.i.d. over the panels. If the  $\mu_i$  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  $\mu_i$  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  $\mu_i$  in the sample. See Mundlak (1978) and Hsiao (2014) 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,  $\text{age}^2$ , 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 https://www.stata-press.com/data/r18/nlswork
(National Longitudinal Survey of Young Women, 14-24 years old in 1968)
. xtreg ln_w age c.age#c.age tenure not_smsa union south, fe
Fixed-effects (within) regression      Number of obs   =   19,007
Group variable: idcode                Number of groups =    4,134
R-squared:                            Obs per group:
    Within = 0.1333                    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	Coefficient	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					
sigma_e	.25545969					
rho	.70091004	(fraction of variance due to u_i)				

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   =   19,007
Group variable: idcode                   Number of groups =    4,134
R-squared:                               Obs per group:
    Within = .                               min =           1
    Between = 0.1304                         avg =           4.6
    Overall = 0.0897                         max =           12
                                           Wald chi2(4)    =  147926.58
                                           Prob > chi2     =    0.0000
corr(u_i, Xb) = -0.6843

```

ln_wage	Coefficient	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		

Endogenous: tenure

Exogenous: 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  $\mu_i$  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  $\mu_i$  and the variance of the  $\nu_{it}$ . 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 `ec2s1s` 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 passing each of the variables in  $\mathbf{X}_{it}$  through the within transform, and  $\bar{\mathbf{X}}_{it}$  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      =      19,007
Group variable: idcode                  Number of groups   =       4,134
R-squared:                               Obs per group:
    Within = 0.0664                       min =              1
    Between = 0.2098                       avg =              4.6
    Overall = 0.1463                       max =              12
                                           Wald chi2(5)       =      1446.37
                                           Prob > chi2        =       0.0000
```

ln_wage	Coefficient	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)				

Endogenous: tenure

Exogenous: 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   =   19,007
Group variable: idcode                   Number of groups =    4,134
R-squared:                               Obs per group:
    Within = 0.0898                       min =           1
    Between = 0.2608                      avg =           4.6
    Overall = 0.1926                      max =           12
                                           Wald chi2(5)    =   2721.92
                                           Prob > chi2     =    0.0000
corr(u_i, X) = 0 (assumed)
```

ln_wage	Coefficient	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)				

Endogenous: tenure

Exogenous: 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      Number of obs   =   19,007
Group variable: idcode                  Number of groups =    4,134
R-squared:                               Obs per group:
    Within = 0.0664                      min =           1
    Between = 0.2098                     avg =           4.6
    Overall = 0.1463                     max =           12
                                         Wald chi2(5)    =   1446.93
corr(u_i, X) = 0 (assumed)              Prob > chi2     =    0.0000
```

ln_wage	Coefficient	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)				

Endogenous: tenure  
 Exogenous: 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  $\mu_i$  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 slightly different because Arellano and Bond are using robust standard errors from GMM while we obtain our robust standard errors from 2SLS.

```
. use https://www.stata-press.com/data/r18/abdata
. xtivreg n l2.n l(0/1).w l(0/2).(k ys) yr1981-yr1984 (l.n = l3.n), fd vce(robust)
First-differenced IV regression
Group variable: id                Number of obs    =    471
Time variable: year              Number of groups =    140
R-squared:                        Obs per group:
    Within = 0.0141                min =           3
    Between = 0.9165               avg =          3.4
    Overall = 0.9892               max =           5
                                Wald chi2(14)     =   259.49
corr(u_i, Xb) = 0.9239            Prob > chi2      =    0.0000
                                (Std. err. adjusted for 140 clusters in id)
```

D.n	Coefficient	Robust std. err.	z	P> z	[95% conf. interval]	
<b>n</b>						
LD.	1.422765	1.019992	1.39	0.163	-.5763824	3.421913
L2D.	-.1645517	.1300598	-1.27	0.206	-.4194643	.0903609
<b>w</b>						
D1.	-.7524675	.2341305	-3.21	0.001	-1.211355	-.29358
LD.	.9627611	.7828358	1.23	0.219	-.5715688	2.497091
<b>k</b>						
D1.	.3221686	.1066645	3.02	0.003	.1131099	.5312273
LD.	-.3248778	.3933448	-0.83	0.409	-1.095819	.4460637
L2D.	-.0953947	.1257672	-0.76	0.448	-.3418938	.1511045
<b>ys</b>						
D1.	.7660906	.3172664	2.41	0.016	.14426	1.387921
LD.	-1.361881	.8980497	-1.52	0.129	-3.122026	.3982639
L2D.	.3212993	.4234835	0.76	0.448	-.508713	1.151312
<b>yr1981</b>						
D1.	-.0574197	.0323419	-1.78	0.076	-.1208088	.0059693
<b>yr1982</b>						
D1.	-.0882952	.0580339	-1.52	0.128	-.2020395	.0254491
<b>yr1983</b>						
D1.	-.1063153	.0934136	-1.14	0.255	-.2894026	.0767719
<b>yr1984</b>						
D1.	-.1172108	.1150944	-1.02	0.308	-.3427917	.1083701
_cons	.0161204	.025376	0.64	0.525	-.0336155	.0658564
sigma_u	.29069213					
sigma_e	.34152632					
rho	.42011045	(fraction of variance due to u_i)				

Endogenous: L.n  
 Exogenous: 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(N_clust)</code>	number of clusters
<code>e(sigma)</code>	ancillary parameter ( $\gamma$ , $I_{\text{normal}}$ )
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(r2_w)</code>	$R^2$ for within model
<code>e(r2_o)</code>	$R^2$ for overall model
<code>e(r2_b)</code>	$R^2$ for between model
<code>e(chi2)</code>	$\chi^2$
<code>e(rho)</code>	$\rho$
<code>e(F)</code>	model $F$ (small only)
<code>e(m_p)</code>	$p$ -value from model test
<code>e(thta_min)</code>	minimum $\theta$
<code>e(thta_5)</code>	$\theta$ , 5th percentile
<code>e(thta_50)</code>	$\theta$ , 50th percentile
<code>e(thta_95)</code>	$\theta$ , 95th percentile
<code>e(thta_max)</code>	maximum $\theta$
<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(endog)</code>	names of endogenous variables
<code>e(exog)</code>	names of exogenous variables
<code>e(model)</code>	<code>g2s1s</code> or <code>ec2s1s</code>
<code>e(small)</code>	small, if specified
<code>e(clustvar)</code>	name of cluster variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ 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
<code>e(V_modelbased)</code>	model-based variance

### Functions

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

In addition to the above, the following is stored in `r()`:

Matrices	
<code>r(table)</code>	matrix containing the coefficients with their standard errors, test statistics, $p$ -values, and confidence intervals

Note that results stored in `r()` are updated when the command is replayed and will be replaced when any `r-class` command is run after the estimation command.

`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>	$R^2$ for within model
<code>e(r2_o)</code>	$R^2$ for overall model
<code>e(r2_b)</code>	$R^2$ for between model
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	model Wald
<code>e(chi2_p)</code>	$p$ -value for model $\chi^2$ 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(endog)</code>	names of endogenous variables
<code>e(exog)</code>	names of exogenous variables
<code>e(model)</code>	<code>be</code>
<code>e(small)</code>	<code>small</code> , if specified
<code>e(clustvar)</code>	name of cluster variable
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(vctype)</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
<code>e(V_modelbased)</code>	model-based variance

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



In addition to the above, the following is stored in `r()`:

Matrices	
<code>r(table)</code>	matrix containing the coefficients with their standard errors, test statistics, $p$ -values, and confidence intervals

Note that results stored in `r()` are updated when the command is replayed and will be replaced when any `r-class` command is run after the estimation command.

`xtivreg, fe` 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(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 the within-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(N_clust)</code>	number of clusters
<code>e(sigma)</code>	ancillary parameter ( $\gamma$ , $\lnormal$ )
<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 $\epsilon_{it}$
<code>e(r2_w)</code>	$R^2$ for within model
<code>e(r2_o)</code>	$R^2$ for overall model
<code>e(r2_b)</code>	$R^2$ for between model
<code>e(chi2)</code>	model Wald (not small)
<code>e(chi2_p)</code>	$p$ -value for model $\chi^2$ test
<code>e(rho)</code>	$\rho$
<code>e(F)</code>	$F$ statistic (small only)
<code>e(F_f)</code>	$F$ for $H_0: u_i=0$
<code>e(F_fp)</code>	$p$ -value for $F$ for $H_0: u_i=0$
<code>e(df_a)</code>	degrees of freedom for absorbed effect
<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(endog)</code>	names of endogenous variables
<code>e(exog)</code>	names of exogenous variables
<code>e(model)</code>	<code>fe</code>
<code>e(small)</code>	small, if specified
<code>e(clustvar)</code>	name of cluster variable
<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
<code>e(V_modelbased)</code>	model-based variance

Functions  
`e(sample)` marks estimation sample

In addition to the above, the following is stored in `r()`:

Matrices  
`r(table)` matrix containing the coefficients with their standard errors, test statistics,  $p$ -values, and confidence intervals

Note that results stored in `r()` are updated when the command is replayed and will be replaced when any `r`-class command is run after the estimation command.

`xtivreg`, `fd` 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 first-differenced regression  
`e(g_min)` smallest group size  
`e(g_avg)` average group size  
`e(g_max)` largest group size  
`e(N_clust)` number of clusters  
`e(sigma)` ancillary parameter ( $\gamma$ ,  $lnormal$ )  
`e(corr)`  $corr(u_i, Xb)$   
`e(sigma_u)` panel-level standard deviation  
`e(sigma_e)` standard deviation of  $\epsilon_{it}$   
`e(r2_w)`  $R^2$  for within model  
`e(r2_o)`  $R^2$  for overall model  
`e(r2_b)`  $R^2$  for between model  
`e(chi2)` model Wald (not `small`)  
`e(chi2_p)`  $p$ -value for model  $\chi^2$  test  
`e(rho)`  $\rho$   
`e(F)`  $F$  statistic (`small` only)  
`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(endog)` names of endogenous variables  
`e(exog)` names of exogenous variables  
`e(model)` `fd`  
`e(small)` `small`, if specified  
`e(clustvar)` name of cluster variable  
`e(vce)` `vce`type specified in `vce()`  
`e(vctype)` title used to label Std. err.  
`e(properties)` `b V`  
`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  
`e(V_modelbased)` model-based variance

Functions  
`e(sample)` marks estimation sample

In addition to the above, the following is stored in `r()`:

Matrices	
<code>r(table)</code>	matrix containing the coefficients with their standard errors, test statistics, <i>p</i> -values, and confidence intervals

Note that results stored in `r()` are updated when the command is replayed and will be replaced when any *r*-class command is run after the estimation command.

## Methods and formulas

Consider an equation of the form

$$y_{it} = \mathbf{Y}_{it}\boldsymbol{\gamma} + \mathbf{X}_{1it}\boldsymbol{\beta} + \mu_i + \nu_{it} = \mathbf{Z}_{it}\boldsymbol{\delta} + \mu_i + \nu_{it} \tag{2}$$

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  $\nu_{it}$ ;

$\mathbf{X}_{1it}$  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  $\mu_i$  removed by differencing, we can obtain the estimated coefficients and their estimated variance–covariance matrix from a two-stage least-squares regression of  $\Delta y_{it}$  on  $\Delta \mathbf{Z}_{it}$  with instruments  $\Delta \mathbf{X}_{it}$ .

$R^2$  within is reported as  $\left[ \text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\widehat{\boldsymbol{\delta}}, y_{it} - \bar{y}_i\} \right]^2$ .

$R^2$  between is reported as  $\left\{ \text{corr}(\bar{\mathbf{Z}}_i\widehat{\boldsymbol{\delta}}, \bar{y}_i) \right\}^2$ .

$R^2$  overall is reported as  $\left\{ \text{corr}(\mathbf{Z}_{it}\widehat{\boldsymbol{\delta}}, y_{it}) \right\}^2$ .

**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

$$\bar{w}_i. = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it}$$

$$\bar{w} = \frac{1}{N} \sum_{i=1}^n \sum_{t=1}^{T_i} w_{it}$$

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  $\mu_i$ . With the  $\mu_i$  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. The robust and cluster-robust variance-covariance matrices are the robust and cluster-robust variance-covariance matrices from a two-stage least-squares regression of  $\tilde{y}_{it}$  on  $\tilde{\mathbf{Z}}_{it}$  with instruments  $\tilde{\mathbf{X}}_{it}$ .

From the estimate of  $\hat{\boldsymbol{\delta}}$ , estimates  $\hat{\mu}_i$  of  $\mu_i$  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  $\nu_{it}$  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  $\mu_i$  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

$$\bar{y}_i = \alpha + \bar{\mathbf{Z}}_i \boldsymbol{\delta} + \mu_i + \bar{\nu}_i \tag{3}$$

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 VCE, a two-stage least-squares regression of  $\bar{y}_i$  on  $\bar{Z}_i$  with instruments  $\bar{\mathbf{X}}_i$  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,

$$E(uu') = \sigma_\nu^2 \text{diag} \left[ I_{T_i} - \frac{1}{T_i} \boldsymbol{\nu}_{T_i} \boldsymbol{\nu}'_{T_i} \right] + \text{diag} \left[ w_i \frac{1}{T_i} \boldsymbol{\nu}_{T_i} \boldsymbol{\nu}'_{T_i} \right]$$

where

$$\omega_i = T_i \sigma_\mu^2 + \sigma_\nu^2$$

and  $\boldsymbol{\nu}_{T_i}$  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  $\bar{u}_i^b$  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

$$r = \text{trace} \left\{ \left( \overline{\mathbf{Z}}_i' \overline{\mathbf{Z}}_i \right)^{-1} \overline{\mathbf{Z}}_i' \mathbf{Z}_\mu \mathbf{Z}_\mu' \overline{\mathbf{Z}}_i \right\}$$

where

$$\mathbf{Z}_\mu = \text{diag} \left( \boldsymbol{\nu}_{T_i} \boldsymbol{\nu}_{T_i}' \right)$$

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

$$\hat{\sigma}_\mu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \tilde{u}_{it}^2 - n \hat{\sigma}_\nu^2}{N}$$

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 covariates 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 VCE from an instrumental variable regression of  $y_{it}^*$  on  $\mathbf{Z}_{it}^*$  with instruments  $\mathbf{X}_{it}^*$ .

If the `ec2s1s` 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  $\sqrt{\widehat{\sigma}_\mu^2 + \widehat{\sigma}_\nu^2}$ .

$R^2$  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  $\left\{ \text{corr}(\mathbf{Z}_{it} \widehat{\boldsymbol{\delta}}, y_{it}) \right\}^2$ .

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## Also see

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

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

[XT] **xteregress** — Extended random-effects linear regression

[XT] **xthtaylor** — Hausman–Taylor estimator for error-components models

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

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

[R] **ivregress** — Single-equation instrumental-variables regression

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

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