Difference-in-Differences in Stata 17

StataCorp LLC

August 5-6, 2021
Difference-in-differences (DID)

- One of the most popular causal effects estimators (1855)
- Understand the effect of a treatment on an outcome for the treated group
  - Subsidy on productivity
  - A drug on cholesterol levels
  - An after-school program on GPA
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  - Observational data for repeated cross-sectional and panel data
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  - Observational data for repeated cross-sectional and panel data
  - Identification does not depend on controlling for covariates
  - Identification hinges on control for group and time unobservable characteristics
- Estimate of causal effect of a treatment controlling for unobservables
Stata implementation

- Two-way fixed effects also known as generalized DID (default)
- Allows 2x2 design
- Provides a wide range of standard errors
- Provides diagnostics and tests
- Binary or continuous treatment
- Difference-in-difference-in-differences (DDD) with group and time interactions
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- Allows 2x2 design
- Provides a wide range of standard errors
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Caveats

- Treatment effects are homogeneous
- Standard error literature is large and growing
- Diagnostics and tests
Outline

- Basic concepts
- Stata examples
Basic Concepts
Treated group
What have we learned

- Clearly there is a change in the outcome after treatment for the treated
- Is it causal?
  - Group unobservable characteristics correlated to treatment. Jargon.
What have we learned

- Clearly there is a change in the outcome after treatment for the treated
- Is it causal?
  - Group unobservable characteristics correlated to treatment. Jargon.
- What can we do?
  - Control for time-specific effects
  - Control for group-specific unobservables (fixed-effects)
  - Use a causal-inference framework
Graphical representation I
Card and Krueger (1994)

- Intervention: Increase in the minimum wage
- Group: New Jersey and Pennsylvania
- Outcome: Employment
Individuals \((i)\) in a state \((s)\) at two time period \(t \in \{0, 1\}\)

Potential outcomes (for now no covariates):

\[
E(y_{ist0}|s, t) = \lambda_t + \gamma_s \\
E(y_{ist1}|s, t) = \lambda_t + \gamma_s + \beta
\]

- \(\lambda_t\) is a time effect
- \(\gamma_s\) is a state effect

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- Individuals \( (i) \) in a state \( (s) \) at two time period \( t \in \{0, 1\} \)
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E (y_{ist1} | s, t) = \lambda_t + \gamma_s + \beta
\]

- \( \lambda_t \) is a time effect
- \( \gamma_s \) is a state effect
- \( y_{ist1} \) is only observed if state \( s \) at time \( t \) receives the treatment, an increase in minimum wage, \( D_{st} = 1 \)
- \( y_{ist0} \) is only observed if state \( s \) at time \( t \) does not receive the treatment, \( D_{st} = 0 \)
Card and Krueger (1994) continued

- New Jersey increased minimum wage in April (treatment)
- Neighboring Pennsylvania did not (control)
- Before wage change in February:

\[
E (y_{ist} | PA, Feb) = \lambda_{Feb} + \gamma_{PA} \\
E (y_{ist} | NJ, Feb) = \lambda_{Feb} + \gamma_{NJ} \\
E (y_{ist} | NJ, Feb) - E (y_{ist} | PA, Feb) = \gamma_{NJ} - \gamma_{PA}
\]
Card and Krueger (1994) continued

- New Jersey increased minimum wage in April (treatment)
- Neighboring Pennsylvania did not (control)
- Before wage change in February:

\[
E(y_{ist}|PA, Feb) = \lambda_{Feb} + \gamma_{PA} \\
E(y_{ist}|NJ, Feb) = \lambda_{Feb} + \gamma_{NJ} \\
E(y_{ist}|NJ, Feb) - E(y_{ist}|PA, Feb) = \gamma_{NJ} - \gamma_{PA}
\]

- The model assumes a common time trend and differing state effects
- Differencing eliminates unobserved time effects
After the minimum wage change, in November:

\[ E(y_{ist}|NJ, \text{Nov}) - E(y_{ist}|PA, \text{Nov}) = \gamma_{NJ} - \gamma_{PA} + \beta \]

Difference-in-differences looks at differences before and after the policy:

\[ [E(y_{ist}|., \text{Nov}) - E(y_{ist}|., \text{Nov})] - [E(y_{ist}|., \text{Feb}) - E(y_{ist}|., \text{Feb})] \]
After the minimum wage change, in November:

\[ E (y_{ist} | NJ, Nov) - E (y_{ist} | PA, Nov) = \gamma_{NJ} - \gamma_{PA} + \beta \]

Difference-in-differences looks at differences before and after the policy:

\[ [E (y_{ist} | ., Nov) - E (y_{ist} | ., Nov)] - [E (y_{ist} | ., Feb) - E (y_{ist} | ., Feb)] \]

The difference in these two differences is \( \beta \)

It is also the average treatment effect on the treated (ATT)
Parallel trends

- $y_{ist0}$ potential outcome of not being treated
- $D_{st} \equiv D$ if group $s$ was treated at time $t$, $D \in \{0, 1\}$
- $s$ and $t$ are $\in \{0, 1\}$
- At $t = 0$ no one is treated
- Parallel trends:

$$E (y_{ist0} | s = 1, D = 1, t = 1)$$

potential outcome of treated in group $s = 1$ had they remained untreated at $t = 1$
Parallel trends

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potential outcome of treated in group $s = 1$ had they remained untreated at $t = 1$

$$E (y_{ist0}|s = 1, D = 1, t = 1) - E (y_{ist0}|s = 1, D = 1, t = 0) =$$

$$E (y_{ist0}|s = 0, D = 1, t = 1) - E (y_{ist0}|s = 0, D = 1, t = 0)$$

- Could be conditional on covariates
Observed Outcome and Estimating equation

\[ E (y_{ist} \mid s, t) = D_{st} E (y_{ist1} \mid s, t) + (1 - D_{st}) E (y_{ist0} \mid s, t) \]
\[ E (y_{ist} \mid s, t) = D_{st} (\lambda_t + \gamma_s + \beta) + (1 - D_{st}) (\lambda_t + \gamma_s) \]
\[ E (y_{ist} \mid s, t) = \lambda_t + \gamma_s + D_{st}\beta \]

- This suggests fitting a regression model with a dummy variable \( D_{st} \)
- The specification could have regressors
Generalized DID or two-way fixed effects

\[ y_{ist} = \gamma_s + \gamma_t + D_{st}\beta + \varepsilon_{ist} \]

- \( D_{st} \) is an observation level indicator of treatment \( D_{st} \in \{0, 1\} \)
- In panel data if individuals are nested in \( s \) individual effect absorb state effects
- You may include covariates in the specification above
$y_{its} = \gamma_{1 \text{treated}} + \gamma_{1 \text{post}} + 1_{\text{treated}} \times 1_{\text{post}} \beta + \varepsilon_{its}$

- Works when all units are treated at the same time (balanced)
- This model is nested in the generalized DID
  - $1_{\text{treated}}$ is a linear combination of the group dummies
  - $1_{\text{post}}$ is a linear combination of the time dummies
- This model assumes all post periods and all treatment groups are equivalent.
Alternative specifications

- $D_{st}$ is not binary but continuous (intensity of treatment)
- Differences occur between two groups (differencing two group unobservables)
- DDD or triple differences. It incorporates unobservables from two control groups.
  - Number of parameters is large
  - Identification is more challenging
Standard error computation

Treatment occurs at the group level, state, county, country, etc. and time

- Cluster at the group level Bertrand, Dufflo, Mullainathan (2004)
- Few number of elements in the group:
  - Donald and Lang (2007) aggregation and other aggregation methods
  - Wild-cluster bootstrap
  - Bias-corrected standard errors with Bell and McCaffrey (2002) degrees of freedom adjustment
- Other suggestions
Stata Examples
. webuse hospdd, clear
(Artificial hospital admission procedure data)
. describe
Contains data from https://www.stata-press.com/data/r17/hospdd.dta
Observations: 7,368
Variables: 5

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<thead>
<tr>
<th>Variable name</th>
<th>Storage type</th>
<th>Display format</th>
<th>Value label</th>
<th>Variable label</th>
</tr>
</thead>
<tbody>
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<td>byte</td>
<td>%9.0g</td>
<td></td>
<td>Hospital ID</td>
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<td>frequency</td>
<td>byte</td>
<td>%9.0g</td>
<td>size</td>
<td>Hospital visit frequency</td>
</tr>
<tr>
<td>month</td>
<td>byte</td>
<td>%8.0g</td>
<td>mnth</td>
<td>Month</td>
</tr>
<tr>
<td>procedure</td>
<td>byte</td>
<td>%9.0g</td>
<td>pol</td>
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</tr>
<tr>
<td>satis</td>
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<td>%9.0g</td>
<td></td>
<td>Patient satisfaction score</td>
</tr>
</tbody>
</table>

Sorted by: hospital
Graphical representation III

![Graphical representation III](image-url)
```plaintext
. didregress (satis) (procedure), group(hospital) time(month)
Number of groups and treatment time
Time variable: month
Control: procedure = 0
Treatment: procedure = 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>hospital</td>
<td>28</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Difference-in-differences regression
Number of obs = 7,368
Data type: Repeated cross-sectional (Std. err. adjusted for 46 clusters in hospital)

| satis         | Coefficient | Robust std. err. | t     | P>|t| | [95% conf. interval] |
|---------------|-------------|------------------|-------|------|----------------------|
| ATET procedure (New vs Old) | .8479879 | .0321121 | 26.41 | 0.000 | .7833108 .912665 |

Note: ATET estimate adjusted for group effects and time effects.
```
Diagnostic plots

- estat trendplot
  - First plot: Mean of the outcome for treated and untreated units
  - Second plot: Trend of treated and control groups (group interacted with time)
Diagnostic plots

Graphical diagnostics for parallel trends

Oberved means

Linear-trends model

Patient satisfaction score vs. Month for Control and Treatment groups.
Tests: estat ptrends

. estat ptrends
Parallel-trends test (pretreatment time period)
H0: Linear trends are parallel
F(1, 45) = 0.55
Prob > F = 0.4615

Augmented model with trends for treated vs. control group before and after treatment. Test if the pretreatment trends are parallel.
Tests: estat granger

. estat granger
Granger causality test
H0: No effect in anticipation of treatment
F(2, 45) = 0.33
Prob > F = 0.7239

- Augment the model to include dummies as if treatment had occurred in the past. Test coefficients jointly.
A 2 × 2 specification

- Create dummy variables for treated group and post time period
- Tell `didregress` not to include group and time effects
- Add dummies to the outcome equation
A 2 × 2 specification

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- Tell `didregress` not to include group and time effects
- Add dummies to the outcome equation

```
. bysort hospital: egen treated = mean(procedure)
. replace treated = 1 if treated>0
   (3,064 real changes made)
. generate post = 0
. replace post = 1 if month>3
   (3,684 real changes made)
```
A 2 × 2 specification

```
. didregress (satis treated post) (procedure), ///
   > group(hospital) time(month) nogteffects
Number of groups and treatment time
Time variable: month
Control: procedure = 0
Treatment: procedure = 1

<table>
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|-------|-------------|------------------|------|-----|----------------------|
| ATET  | procedure   |                  |      |     |                      |
|       | (New vs Old) |                  |      |     |                      |
|       | .8479879    | .0320051         | 26.50| 0.000| .7835263             | .9124494 |

Note: ATET estimate adjusted for covariates.
Augmented DID
Difference-in-difference-in-differences (DDD)

- Augmented DID
- Selection on unobservables provides identification
- What if there are unobservables that vary at the group and time level
- Find a new group not exposed to treatment but exposed to the problematic time-varying confounder
- Subtract the effect of that group from the original DID
Augmented DID

Selection on unobservables provides identification

What if there are unobservables that vary at the group and time level

Find a new group not exposed to treatment but exposed to the problematic time-varying confounder

Subtract the effect of that group from the original DID

In our example think about individual’s frequency of visit affecting satisfaction
. generate hightrt = procedure==1 & (frequency==3 | frequency==4)
. label define trt 0 "Untreated" 1 "Treated"
. label values hightrt trt
DDD estimation

```
吸.regress (satis) (hightrt), group(hospital frequency) time(month)
(output omitted)
Number of groups and treatment time
Time variable: month
Control:  hightrt = 0
Treatment:  hightrt = 1

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
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</tr>
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<tbody>
<tr>
<td>Group</td>
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<tr>
<td>hospital</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>frequency</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>1</td>
<td>4</td>
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</tr>
</tbody>
</table>

Triple-differences regression
Number of obs = 7,368
Data type: Repeated cross-sectional
(Std. err. adjusted for 46 clusters in hospital)

|                | Coefficient | Robust std. err. | t | P>|t| | [95% conf. interval] |
|----------------|-------------|------------------|---|------|----------------------|
| ATET           |             |                  |   |      |                      |
| hightrt (Treated vs Untreated) | .764154 | .0402603 | 18.98 | 0.000 | .6830655 .8452425 |

Note: ATET estimate adjusted for group effects, time effects, and group- and time-effects interactions.
```
Other estimation alternatives

- `didregress (y x1 ... xk) (c, continuous), ...
- `didregress (y ...) (d...), group(g1 g2)
- `xtdidregress (y x1 ... xk) (d), group(groupvar) time(timevar)
Standard error considerations

- Default standard errors are cluster robust standard errors at the group level BDM (2004)
- `didregress` is equivalent to `areg` considers group fixed effects as regressors in the degrees of freedom adjustment
- `xtdidregress` is equivalent to `xtreg` does not consider group fixed effects as regressors
- When the number of elements per groups (states, counties, countries) is small cluster robust standard errors do not work well. Alternatives are:
  - Wild cluster bootstrap
  - Bias corrected standard errors
  - Aggregation methods
Wild-cluster bootstrap

- Covariates remain the same across iteration
- We impose the null hypothesis of $ATET = 0$
- What changes is the weights given to residuals at each iteration
  \[ \tilde{y} = X\tilde{\beta} + \tilde{\varepsilon}, \tilde{\beta}, \text{ and } \tilde{\varepsilon} = \hat{\varepsilon} \ast w \]
- No standard errors are computed (rely on normal approximation)
- P-values and confidence intervals are computed
- Algorithm computes p-values and then solves a bisection-algorithm to get CI
- Problem to find CI upper bound and CI lower bound are two separate optimization problems
Wild-cluster bootstrap

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- P-values and confidence intervals are computed
- Algorithm computes p-values and then solves a bisection-algorithm to get CI
- Problem to find CI upper bound and CI lower bound are two separate optimization problems
- Speed is substantially improved for the next update
## Error weights

<table>
<thead>
<tr>
<th>Error weight</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>rademacher</td>
<td>-1 with pr 0.5 and 1 with pr 0.5</td>
</tr>
<tr>
<td>mammen</td>
<td>$1 - \phi$ with pr $\phi/\sqrt(5)$, $\phi$ otherwise, $\phi = (1 + \sqrt{5})/2$</td>
</tr>
<tr>
<td>webb</td>
<td>$-\sqrt{3}/2, -\sqrt{2}/2, -\sqrt{1}/2, \sqrt{1}/2, \sqrt{2}/2, \sqrt{3}/2$ pr 1/6</td>
</tr>
<tr>
<td>normal</td>
<td>standard normal</td>
</tr>
<tr>
<td>gamma</td>
<td>shape parameter 4 scale parameter 1/2</td>
</tr>
</tbody>
</table>
didregress (satis) (procedure), ///
group(hospital) time(month) wildbootstrap(rseed(111))
computing 1000 replications
Finding p-value
................................................................. 50%
................................................................. 100%
Confidence interval lower bound
.....
Confidence interval upper bound
...........
(output omitted)
. didregress (satis) (procedure), ///
>   group(hospital) time(month) wildbootstrap(rseed(111))

(output omitted)

Number of groups and treatment time
Time variable: month
Control: procedure = 0
Treatment: procedure = 1

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<td>4</td>
</tr>
</tbody>
</table>

DID with wild-cluster bootstrap inference
Number of obs = 7,368
No. of clusters = 46
Replications = 1,000

Data type: Repeated cross-sectional
Error weight: rademacher

| satis | Coefficient | t  | P>|t| | [95% conf. interval] |
|-------|-------------|----|-----|---------------------|
| ATET  | procedure   | .8479879  | 26.41 | 0.000 | .7806237 | .9157614 |

Note: ATET estimate adjusted for group effects and time effects.
Bias-corrected standard errors

- Cluster generalization of HC2 (scale residuals inverse of square of diagonals from projection matrix)
- Bell and McCaffrey (2002) suggest a degrees of freedom adjustment (per parameter)
Bias-corrected SEs

```
. didregress (satis) (procedure), group(hospital) time(month) vce(hc2)
Computing degrees-of-freedom:
procedure ...........
Number of groups and treatment time
Time variable: month
Control: procedure = 0
Treatment: procedure = 1

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment</th>
</tr>
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<tbody>
<tr>
<td>Group</td>
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<tr>
<td>hospital</td>
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<td>18</td>
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<td>Minimum</td>
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<tr>
<td>Maximum</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
```

Difference-in-differences regression

Data type: Repeated cross-sectional

```
Number of obs  = 7,368
No. of clusters = 46

| satis | Coefficient | std. err. | t     | P>|t|  | [95% conf. interval] |
|-------|-------------|-----------|-------|-----|---------------------|
| ATET  | procedure   |           |       |     |                     |
| (New  | vs Old)     |           |       |     |                     |
|       | .8479879    | .0325552  | 26.05 | 0.000 | .7819941 .9139816   |
```

Note: ATET estimate adjusted for group effects and time effects.
Degrees of freedom adjustment

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<th>Controls:</th>
<th>Controls:</th>
<th>Controls:</th>
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<table>
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<tr>
<th>Procedure</th>
<th>Controls:</th>
<th>Controls:</th>
</tr>
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<tbody>
<tr>
<td>b</td>
<td>-0.00383754</td>
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<tr>
<td>se</td>
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<td>0.01140018</td>
</tr>
<tr>
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<td>-2.013216</td>
<td>302.1596</td>
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<td>4.517e-76</td>
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(StataCorp LLC)
Aggregation methods

\[ y_{its} = \gamma_s + \gamma_t + z_{1ist} \beta_1 + z_{2st} \beta_2 + D_{st} \delta + \varepsilon_{ist} \]

\[ y_{ist} = z_{1ist} \beta_2 + C_{st} + \varepsilon_{ist} \]

\[ \hat{C}_{st} = z_{2st} \beta_2 + D_{st} \delta + \nu_{st} \]

- Obtain \( \hat{C}_{st} \)
- Aggregate at the \( s, t \) level and regress
  - \text{dlang, constant:} regress \( \hat{C}_{st} \) on \( z_{2st}, D_{st} \) and time and group fixed effects, degrees of freedom are a function of the level of aggregation \( st \)
  - \text{standard:} regress \( \hat{C}_{st} \) on \( z_{2st}, D_{st} \)
  - \text{dlang, varying:} \( \hat{C}_{st} \) is the constant of a regression of each group defined by \( st \), i.e. \( \beta_1 \) is not constant but varying.
. didregress (satis) (procedure), group(hospital) time(month) aggregate(dlang)

Number of groups and treatment time

Time variable: month

Control: procedure = 0
Treatment: procedure = 1

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment</th>
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</thead>
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<table>
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<tr>
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<th>Minimum</th>
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<tbody>
<tr>
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<td>4</td>
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<tr>
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<td>1</td>
<td>4</td>
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Difference-in-differences regression

Number of obs = 322

Data type: Repeated cross-sectional
Aggregation: Donald-Lang

| satis  | Coefficient | Std. err. | t    | P>|t| | [95% conf. interval] |
|--------|-------------|-----------|------|------|---------------------|
| ATET   |             |           |      |      |                     |
| procedure (New vs 0ld) | .8500467 | .0255727 | 33.24 | 0.000 | .7997311 .9003623   |

Note: ATET estimate adjusted for group effects and time effects.
. didregress `specs´, group(hospital) time(month) aggregate(standard) vce(hc2)
Computing degrees-of-freedom:
procedure ...........
Number of groups and treatment time
Time variable: month
Control: procedure = 0
Treatment: procedure = 1

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hospital</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
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<tr>
<td>Minimum</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Maximum</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Difference-in-differences regression
Number of obs = 322
No. of clusters = 46

Data type: Repeated cross-sectional
Aggregation: Standard

<table>
<thead>
<tr>
<th></th>
<th>Robust HC2</th>
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<tbody>
<tr>
<td>satis</td>
<td>Coefficient</td>
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<td>ATET</td>
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<tr>
<td>procedure</td>
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<tr>
<td>(New vs Old)</td>
<td>.8500467</td>
</tr>
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Note: ATET estimate adjusted for group effects and time effects.
Conclusions

- DID and DDD estimation for cross-sectional and panel-data
- Graphical diagnostics and tests to validate identification strategy
- Standard errors for situations with the number of groups is small
- Just a first step from which we will build