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Estimation and testing of fixed-effect panel-data systems

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Abstract. This paper describes how to specify, estimate, and test multiple-equation, fixed-effect, panel-data equations in Stata. By specifying the system of equations as seemingly unrelated regressions, Stata panel-data procedures worked seamlessly for estimation and testing of individual variable coefficients, but additional routines using `test` were needed for testing of individual equations and differences between equations.

Keywords: st0084, panel data, fixed effect, multiple equations, seemingly unrelated regressions, heteroskedasticity, autocorrelation, contemporaneous correlation, tests of linear combinations

1 Introduction

The motivation to develop a multiple-equation panel-data procedure came from a need to determine whether certain laboratory experiments with multiple panels of laboratory animals produced statistically different results. This suggested that each experiment could be treated as a separate equation in a system of seemingly unrelated regressions (SUR), although it was necessary to apply special restrictions prior to estimation. The SUR model described below is a slightly simplified version of one that was developed to estimate and test pairs of laboratory experiments.

2 Framework

The framework for this paper derives from seemingly unrelated regressions with error components (Baltagi 2001, 105–106). It is then assumed that coefficients of constant terms and quantitative independent variables require restriction across the panels in their equations, while fixed-effect dummies vary by panel (Judge et al. 1988, 456–459). Error structures of both equations below were assumed to be characterized by panel heteroskedasticity, panel autocorrelation, and contemporaneous correlation (HPAC). For simplicity, fixed effects were estimated with the dummy variable regression technique (Wooldridge 2002, 272–274). A simple model for exploration of this situation is

$$y_{1it} = b_{10}x_{1it} + b_{11} + v_{1i} + \varepsilon_{1it}; i = 1, 2, \dots, N_1; t = 1, 2, \dots, T \quad (1)$$

$$y_{2it} = b_{20}x_{2it} + b_{21} + v_{2i} + \varepsilon_{2it}; i = N_1 + 1, \dots, N_2; t = 1, 2, \dots, T \quad (2)$$

Equations here are indicated by first subscripts, while other subscripts indicate panels and time periods, as shown. Thus (1) has N_1 panels, T time periods, and N_1 fixed-effect coefficients, $v_{1,1}, v_{1,2}, \dots, v_{1,N_1}$. Likewise, (2) has $N_2 - N_1$ panels, T time periods, and the fixed-effect coefficients $v_{2,1}, v_{2,2}, \dots, v_{2,N_2}$. Thus when (1) and (2) are pooled, we have a total of N_2 panels, with no repetition of time codes within any given panel. This is important because estimation fails when there is multiplicity of time codes within any panel.

The SUR matrix specification for (1) and (2) is

$$\mathbf{y} = \begin{bmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \varepsilon$$

where $\mathbf{y} = [y_{1,1,1}, \dots, y_{1,N_1,T}, y_{2,N_1+1,1}, \dots, y_{2,N_2,T}]'$

$\mathbf{X}_1 = [c_1, x_1, d_{1,2}, \dots, d_{1,N_1}]$ $\mathbf{X}_2 = [c_2, x_2, d_{2,N_1+2}, \dots, d_{2,N_2}]$

$\beta_1 = [b_{1,0}^*, b_{1,1}, v_{1,2}^*, \dots, v_{1,N_1}^*]'$ $\beta_2 = [b_{2,0}^*, b_{2,1}, v_{2,N_1+2}^*, \dots, v_{2,N_2}^*]'$

$d_{1,2}, \dots, d_{1,N_1}$ and $d_{2,N_1+2}, \dots, d_{2,N_2}$ are fixed-effect dummies

$\varepsilon = [\varepsilon_{1,1,1}, \dots, \varepsilon_{1,N_1,T}, \varepsilon_{2,N_1+1,1}, \dots, \varepsilon_{2,N_2,T}]'$

asterisks indicate composite variables

3 Data setup for estimation

In the experimental data described in the introduction, (1) and (2) each had seven panels. Thus the panels of the system were consecutively numbered 1–14, with panels 1–7 assigned to (1) and panels 8–14 assigned to (2). Deletion of one dummy from each equation then left

$$\mathbf{X}_1 = [c_1, x_1, d_2, \dots, d_7] \quad \mathbf{X}_2 = [c_2, x_2, d_9, \dots, d_{14}]$$

Extracting x_1 from \mathbf{X}_1 and x_2 from \mathbf{X}_2 , the vector \mathbf{x} was formed by stacking x_1 and x_2 to correspond with the elements of \mathbf{y} . For purposes of data entry, however, it seemed advisable to unbold \mathbf{y} and \mathbf{x} , since Stata normally uses unbolded lowercase letters in variable names. Thus, the variables \mathbf{y} and \mathbf{x} , along with identifiers for panels, time codes, and equations were input into a Stata dataset. Remaining variables were then created and arranged by running the do-file:

```
. tab eq, gen(c)
. gen x1 = c1*x
. gen x2 = c2*x
. tab pn1, gen(d)
. drop d1 d8
```

```

. move x1 c2
. move d2 c2
...
. move d7 c2

```

Table 1 shows a subset of the full dataset described above, created by selecting the first three panels and time periods from each equation, thus placing panels 1–3 in (1) and panels 8–10 in (2). Table 1 merits close scrutiny because the panel identifiers, time codes, equation codes, and contents of \mathbf{X}_1 and \mathbf{X}_2 accurately reflect the organization and features of the full dataset. For example, examination of \mathbf{X}_1 and \mathbf{X}_2 reveals that a fixed-effect dummy must be deleted from each to avert block-specific dummy variable traps. Thus estimation requires the `nointercept` option, as in the classic SUR specification (Judge et al. 1988, 470).

Table 1: sample dataset

y	x	pnl	week	eq	c1	x1	d2	d3	c2	x2	d9	d10
116	0	1	0	1	1	0	0	0	0	0	0	0
166	0.693	1	1	1	1	0.693	0	0	0	0	0	0
201	1.099	1	2	1	1	1.099	0	0	0	0	0	0
149	0	2	0	1	1	0	1	0	0	0	0	0
197	0.693	2	1	1	1	0.693	1	0	0	0	0	0
230	1.099	2	2	1	1	1.099	1	0	0	0	0	0
126	0	3	0	1	1	0	0	1	0	0	0	0
151	0.693	3	1	1	1	0.693	0	1	0	0	0	0
209	1.099	3	2	1	1	1.099	0	1	0	0	0	0
114	0	8	0	2	0	0	0	0	1	0	0	0
164	0.693	8	1	2	0	0	0	0	1	0.693	0	0
225	1.099	8	2	2	0	0	0	0	1	1.099	0	0
142	0	9	0	2	0	0	0	0	1	0	1	0
206	0.693	9	1	2	0	0	0	0	1	0.693	1	0
262	1.099	9	2	2	0	0	0	0	1	1.099	1	0
120	0	10	0	2	0	0	0	0	1	0	0	1
160	0.693	10	1	2	0	0	0	0	1	0.693	0	1
218	1.099	10	2	2	0	0	0	0	1	1.099	0	1

4 Estimation and testing of fixed-effect panel-data systems

Given that (1) and (2) include fixed effects, the user must choose among FGLS (`xtgls`), OLS with panel-corrected standard errors (PCSE) (`xtpcse`), or fixed-effects regression (`areg` or `xtreg, fe`). This topic is explored at length by Beck and Katz (1995), and

the key issues are neatly summarized by Wiggins (2001). However, only `xtgls` and `xtpcse` have all the options for the HPAC structure, so we will focus on those. See [XT] `xtgls` and [XT] `xtpcse` for details.

When `xtgls` is indicated, the command for HPAC SUR estimation is

```
. xtgls y c1 x1 d2-d7 c2 x2 d9-d14, i(pnl) t(week) p(c) c(psar1) nocon
```

When `xtpcse` is indicated, the commands for HPAC estimation are

```
. tsset pnl week
. xtpcse y c1 x1 d2-d7 c2 x2 d9-d14, c(psar1) nocon
```

Since our dataset has 14 panels and 9 time periods, FGLS is of course ruled out (Beck and Katz 1995, 637), so the output below (slightly edited) was produced with `xtpcse`:

Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)						
Group variable:	pnl		Number of obs	=	126	
Time variable:	week		Number of groups	=	14	
Panels:	correlated (balanced)		Obs per group:	min =	9	
Autocorrelation:	panel-specific AR(1)			avg =	9	
				max =	9	
Estimated covariances	=	105	R-squared	=	X	
Estimated autocorrelations	=	14	Wald chi2(8)	=	X	
Estimated coefficients	=	16	Prob > chi2	=	X	

	Panel-corrected					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
c1	111.5311	6.208398	17.96	0.000	99.36284	123.6993
x1	88.67886	3.943791	22.49	0.000	80.94918	96.40855
d2	27.81103	1.400501	19.86	0.000	25.0661	30.55596
d3	4.477261	3.969675	1.13	0.259	-3.303159	12.25768
d4	15.006611	4.364777	3.45	0.001	6.511306	3.62092
d5	-39.5333	3.116503	-12.69	0.000	-45.64154	-33.42507
d6	-23.79004	2.0549	-11.58	0.000	-27.81757	-19.76251
d7	9.415222	5.07866	1.85	0.064	-.5387687	19.36921
c2	111.6787	8.215256	13.59	0.000	95.57709	127.7803
x2	115.4025	5.231997	22.06	0.000	105.148	125.657
d9	39.92659	3.15385	12.66	0.000	33.74516	46.10803
d10	-22.60235	5.72391	-3.95	0.000	-33.821	-11.38369
d11	-42.55708	5.499978	-7.74	0.000	-53.33684	-31.77732
d12	-28.39879	5.906044	-4.81	0.000	-39.97442	-16.82315
d13	29.44482	1.958789	15.03	0.000	25.60566	33.28397
d14	78.11019	58.09246	1.34	0.179	-35.74894	191.9693
<hr/>						
rhos =	.249791	.0870025	.1838984	.3443183	-.2943893	-0.0062851

The *R*-squared and Wald statistics in the top section of the above output are obliterated for two reasons. First, they include the influences of the fixed-effect dummies, which serve only to control for the influences of unobserved variables ([R] `areg`, Stata 8, 87 or Stata 9, 95; Wooldridge 2003, 465–467). Second, the *R*-squared and Wald statistics in the `xtpcse` output are computed for the entire *system* of equations, which is meaning-

less for either equation individually. Fortunately, individual equations can be properly evaluated with `test`, as discussed below.

The coefficients and panel-corrected standard errors in the main body of the `xtpcse` output are correctly reported and consistent, but inefficient. The reported z statistics assume zero nulls and two-sided alternatives. See Baltagi (2001, 78) for a comparison of the properties of FGLS and OLS with PCSEs.

We can easily obtain Wald statistics for any linear combination of coefficients in the above output (Judge et al. 1988, 456–459). For any particular equation, we can use `test` to obtain the Wald statistic to determine the joint influence of all explanatory variables pertaining to that equation, but not including the influences of the fixed-effect dummies, as explained above. In (1), however, `x1` is the only explanatory variable for which we wish to know the effect on `y`, so the Wald statistic is simply the square of the z -score for `x1`, and the Wald statistic and the z -score are equivalent. Likewise, the z -score for `x2` provides the test for (2). Again, both `x1` and `x2` are tested against zero nulls and two-sided alternatives.

The test for a structural difference requires a joint test of all corresponding coefficients from the two equations in the system, in this case including the constant terms, since these too can vary by equation. For our equations, we thus require two linear restrictions to be jointly tested against two-sided alternatives:

```
. test (c1-c2 = 0) (x1-x2 = 0)
      ( 1)  c1 - c2 = 0
      ( 2)  x1 - x2 = 0
             chi2( 2) = 137.10
             Prob > chi2 = 0.0000
```

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