Panel time-series modeling:
New tools for analyzing `xt` data

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- Edward F. Blackburne III and Mark W. Frank (`xtpmg`)

My own contributions

- `multipurt`
- `xtcd`
- `xtmg`

can be found at SSC, including help files and empirical examples.

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   - Revelance, Approach and References

2. Introduction
   - The two worlds of panel data econometrics
   - Why not just one world?
   - The domain of panel time series

3. Stationarity testing in panels

4. Cross-section dependence testing

5. Cointegration testing

6. Estimation in Heterogeneous Parameter Models

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A new field of panel econometrics

- ‘Panel time-series’ (PTS) or ‘nonstationary panel econometrics’ **deemed of great relevance for development economists**: PWT, UNIDO INDStat, other macro panel datasets all display the data properties discussed here. **Further academic fields** faced with macro panel data: regional science, climate research; data properties likely in a host of other fields, too. Close link to **Gordon Hughes’ talk** yesterday!
- **Relatively new field of study**: Theory starts in early 1990s, most activity over past 5-10 years; relatively few researchers are using the methods; not much accessible literature yet.
- Many of the **theoretical concepts rather intuitive** and ***some* of the methods relatively easy to implement**.
- No **textbook**, but some **introductory readings**: Baltagi (2008, *Econometric Analysis of Panels*, Chapter 12), Coakley, Fuertes, and Smith (2006, *Comp Stats & Data Analysis*) and Eberhardt and Teal (2011, *J Econ Surveys*).

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Micro (‘short T) and Macro (‘long T’) panels

	Macro panels	**Micro panels**
aka	time-series panels	longitudinal panels
N (‘groups’)	moderate, typically < 100; countries, regions	substantial, at times thousands; individuals, firms, households
T	substantial, typically > 20; years; macro-finance: quarters, months	short, < 10, most commonly $T < 5$; typically years
asymptotics	N, $T \rightarrow \infty$, sequ or jointly (restrictions!)	$N \rightarrow \infty$
parameters	study heterogeneity across groups, not just time-invariant FE	homogeneity assumed, FE assumed to pick up all heterogeneity
dynamics	often non-trivial, idiosyncratic	limited to lagged dep. variable, homogeneous
variable properties	unit roots, other nonstationarities (e.g. structural breaks, trends)	stationary data
endogeneity	pervasive, lack of valid instruments	instruments available (incl. own lags)
cross-section dependence	tested and accommodated, but structure not analysed	independence assumed (except: spatial econometrics)
estimators	MG, CCEMG, AMG, PMG, GM-FMOLS	FE, DiffGMM, SysGMM, Olley & Pakes, Levinsohn & Petrin (for productivity analysis)
Stata commands	xtmg	xtreg, xtabond2, opreg, levpet
diagnostic tests	residual properties mean something	‘standard’ output (i.e. not much)

Adapted from Pedroni (2008)

Note: The vast majority of empirical research using ‘macro panels’ implements ‘micro panel’ methods!

Issue #1 Parameter Heterogeneity

If T large enough we can estimate each time-series separately and test for heterogeneity. This raises a question as to **what the parameters of interest are**: the coefficients of the individual units, say β_i for $i = 1, \ldots, N$ or the expected values ('means') and the variances of the coefficients over the groups, $\mathbb{E}[\beta_i]$ and $\mathbb{V}ar[\beta_i]$?

Consider the following example data generating process (read: the true process driving the data), taken from Smith and Fuertes (2007): let

$$y_{it} = \mu_i + \varepsilon_{it} \qquad \mathbb{E}[\varepsilon_{it}] = 0, \mathbb{V}ar[\varepsilon_{it}] = \mathbb{E}[\varepsilon_{it}^2] = \sigma_\varepsilon^2$$

For each group i there is zero-mean variation in y around a constant group-specific mean μ_i. Furthermore, these group-specific means also vary across groups:

$$\mu_i = \mu + \eta_i \qquad \mathbb{E}[\eta_i] = 0, \mathbb{V}ar[\eta_i] = \mathbb{E}[\eta_i^2] = \sigma_\eta^2$$

Issue #1 Parameter Heterogeneity (cont'd)

We can now consider the different means ($\bar{y}$) we can estimate for this very simple example:

$$\begin{aligned}
\bar{y}^{\heartsuit} &= (NT)^{-1}\sum_i\sum_t y_{it} \quad \mathbb{E}[\bar{y}^{\heartsuit}] = \mu \quad \mathbb{V}ar[\bar{y}^{\heartsuit}] = (NT)^{-1}(\sigma_\varepsilon^2 + \sigma_\eta^2) \\
\bar{y}_i^{\clubsuit} &= T^{-1}\sum_t y_{it} \quad \mathbb{E}[\bar{y}_i^{\clubsuit}] = \mu_i \quad \mathbb{V}ar[\bar{y}_i^{\clubsuit}] = T^{-1}\sigma_\varepsilon^2 \\
\bar{y}_t^{\spadesuit} &= N^{-1}\sum_i y_{it} \quad \mathbb{E}[\bar{y}_t^{\spadesuit}] = \mu_t = \mu \quad \mathbb{V}ar[\bar{y}_t^{\spadesuit}] = N^{-1}(\sigma_\varepsilon^2 + \sigma_\eta^2)
\end{aligned}$$

Even in such a simple model setup, we thus obtain very different results: two of the averages are estimates for the **population average** (μ), whereas the third is for the **group-specific average** (μ_i), with variances of the estimators differing across all three. All of them are unbiased and $\{NT, T, N\}$-consistent estimators of **something**, the question is just whether this something is interesting at all… Lesson: what is the statistic of interest? What is the research question?

Issue #2 Variable non-stationarity

Example: cumulative rainfall data for Fortaleza, Northern Brazil, and the evolution of UK per capita GDP. Consider OLS regression

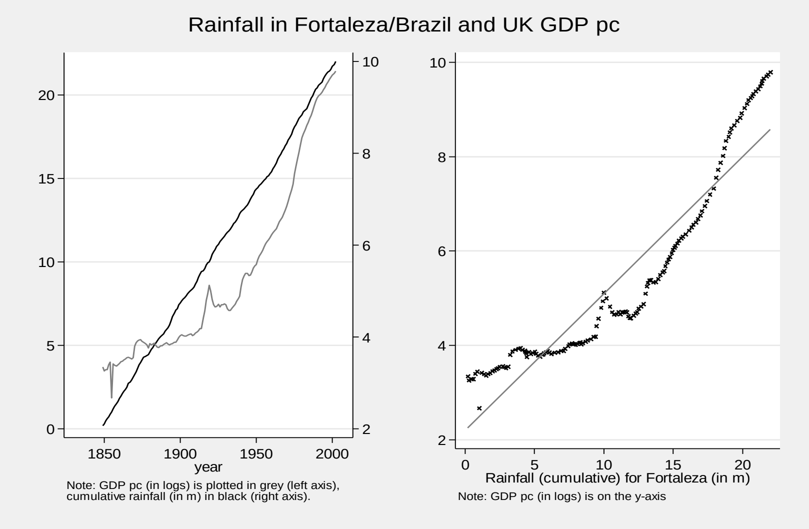
$$\begin{aligned}\log\,(\mathrm{Y/L})_t &= 2.1963\,[t=19.47]+0.2898\,[t=32.53]\,\mathrm{rainfall}_t\\ &\quad R^2=.874 \qquad F(1,152)=1058.23\;(p=.000) \qquad T=154\end{aligned}$$

We get a **positive, statistically significant relationship** between the two variables: seems to suggest that rainfall is a very good predictor of UK per capita GDP (causal relation!?)... however the relationship becomes insignificant if we run the model with variables in first difference (allowing for a drift term):

$$\begin{aligned}\Delta\log\,(\mathrm{Y/L})_t &= 0.0156\,[0.57]+0.1863\,[1.02]\,\Delta\mathrm{rainfall}_t\\ &\quad R^2=.007 \qquad F(1,151)=1.67\;(p=.310) \qquad T=153\end{aligned}$$

⇒ **spurious regression** result of apparent significance in a regression model of two (or more) nonstationary variables. Luckily, we can test for **cointegration** to see whether the relationship is spurious or not.

Issue #2 Variable non-stationarity (con't)



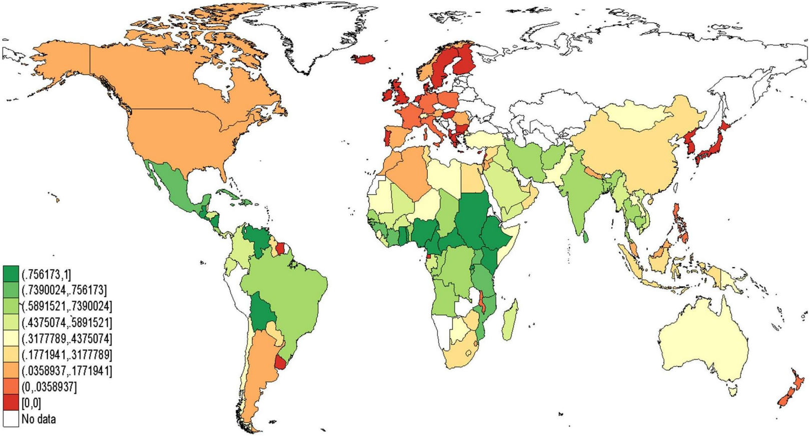
Note: This example is inspired by James Reade's lectures.

Issue #3 Cross-section correlation

- Variable and/or residual **correlation across panel members**: due to common shocks (e.g. recession) or spillover effects.
- **Standard panel estimators** assume cross-section independence.
- If neglected cross-section dependence (CSD) can lead to **imprecise estimates** and at worst to a serious **identification problem**.
- **Example** (next slide): Agro-climatic 'distance' — how similar or different is the climatic environment in agriculture?
- **Spatial econometrics**: econometrician 'knows' how panel members are associated/correlated (e.g. neighbourhood), models this association explicitly employing a weight matrix ('spatially lagged dependent variable'). [Gordon's talk!]
- **Common factor models**: models dependence with unobserved common factors f_t with heterogeneous impact γ_i. Trick is to estimate common factors or blend out their impact on estimation.

Issue #3 Cross-section correlation (cont'd)

Agro-climatic 'distance' — the view from Kenya. Kenya's cultivated land: 40% is located in zone Aw (Equatorial savannah, dry winters), 19% in zone BS (steppe), 17% in zone BW (desert) and 25% in zone H (highland climate). Source: Matthews (1983), in Gallup, Mellinger, and Sachs (1999).



Taken from: Eberhardt & Teal (2011) 'No mangos in the tundra: spatial heterogeneity in agricultural productivity analysis', Working paper.

Existing methods won't do…

- **Apply DiffGMM, SysGMM**: macro panels now arguably main playground for this type of estimators, even though they were developed for large N, short T! Problems: require stationary variables or at least stationarity in the initial condition ($t = 0$ SysGMM); overfitting problem with long T panels; assume parameter homogeneity for instrumentation (see Pesaran & Smith, 1995); assume cross-section independence.
- **Treat as large system of equations: VAR, VECM**: For $Z'_{it} = (y_{it}, X'_{it})$ a panel can be thought of as

$$\Delta Z_t^* = c + \Pi Z_{t-1}^* + \sum_{m=1}^{M} \Phi_m \Delta Z_{t-k}^* + \varepsilon_t^*$$

  Problem: general VECM quickly becomes infeasible as N rises: exponential growth of parameters to be estimated.

So when are Panel Time Series methods most appropriate?

1. **time-dimension** T
   - too short for reliable inference for any single group alone…
   - …but long enough to deal with dynamics flexibly.
2. **cross-section dimension** N
   - too large to be treated as a system (as in the VECM)…
   - …but not so large as to 'overwhelm' the T dimension (many tests require $T/N \to 0$ for asymptotics).
3. data properties
   - some processes are **nonstationary** s.t. cointegration is a possibility for some groups in the panel.
   - potential for **heterogeneity** in the relationship across groups, dynamics non-trivial.
   - some **commonality** exists across groups — if no commonalities, then nothing is gained by combining the information to a panel compared to a time-series.
   - **cross-section dependence** may be an issue (variable in country i may be non-spuriously correlated with variable in country j; unobserved factors common to all countries)

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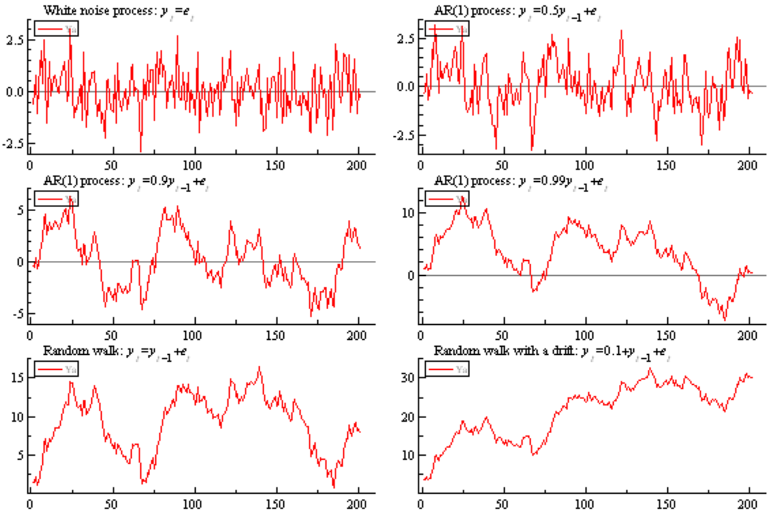
Examples of stochastic processes



Notes: These graphs were produced in OxMetrics 5 using PcNaive.

Stationary testing in time-series land

$$\begin{aligned} y_t &= a + \rho y_{t-1} + \varepsilon_t \\ \Leftrightarrow \Delta y_t &= a + \underbrace{(\rho - 1)}_{b} y_{t-1} + \varepsilon_t = a + b y_{t-1} + \varepsilon_t \end{aligned} \tag{1}$$

If $\rho = 1 \Leftrightarrow b = 0$ this collapses to $\Delta y_t = a + \varepsilon_t$

Dickey-Fuller (DF) test: One way of testing the unit root hypothesis $H_0 : \rho = 1$ is to compute the t-ratio for y_{t-1} in equation (1). Since this involves a definitely I(0) variable on the LHS and a potentially I(1) variable on the RHS the t-ratio does not have a standard t-distribution, but 'Dickey-Fuller distribution'.
The **Augmented Dickey-Fuller (ADF) test** takes potential serial correlation in the error term into account — this is achieved by introducing lagged terms of the dependent variable. Alternative testing procedures use other parametric or nonparametric techniques to wash out serial correlation.

The trouble with time-series unit root tests

Single time-series test might not reject H_0, but we'd still doubt data is I(1):

- ★ low power of the tests in near-unit root case
- inference is sensitive to treatment of serially correlated errors and treatment of means and trends
- sensitivity to structural breaks
- power dependence on time span: short (decades) time-series look I(1), long ones (century) I(0)
- non-linearities

★ by far the most serious short-coming. Consider the power statistics for time-series unit root tests:

AR coefficient	DF	ADF	PP
0.25	0.90	0.93	0.95
0.65	0.25	0.78	0.89
0.95	0.09	0.15	0.20

Recall: 'power' of a test is its ability to reject the null when it is false; 'size' is the probability of rejecting the null when it is actually true.

PURT implementations in Stata

- First generation PURTs
  - Levin and Lin (1992) pooled ADF test (`levinlin`)
  - Im, Pesaran, and Shin (1997) averaged unit root test for heterogeneous panels (IPS) (`ipshin`)
  - Maddala and Wu (1999) Fisher combination test (MW) (`xtfisher`)
  - Breitung (2000), Hadri (2000), Harris & Tzavalis (1999) (`xtunitroot` with options `breitung, hadri, ht`, respectively, in addition to the above tests)
- Second generation PURTs
  - Pesaran (2007) panel unit root test (`pescadf`)
  - Pesaran, Smith, and Yamagata (2009) panel unit root test (`xtcipsm` under construction)
- Convenient tool
  - `multipurt` combines `xtfisher` and `pescadf` but allows multiple variables and ranges of lag augmentations.
- Alternative approaches currently unavailable
  - Bai and Ng (2004) PANIC attack

Practical example

Maddala and Wu (1999) Fisher Test

	Constant			
lags	ln Y_{it}	ln L_{it}	ln K_{it}	ln R_{it}
0	377.10 (.00)	195.89 (.98)	475.55 (.00)	821.56 (.00)
1	387.37 (.00)	318.94 (.00)	353.65 (.00)	376.22 (.00)
2	329.96 (.00)	184.69 (.99)	277.02 (.04)	373.42 (.00)
3	292.94 (.01)	211.53 (.89)	329.64 (.00)	361.32 (.00)

Pesaran (2007) CIPS Test

	Constant			
lags	ln Y_{it}	ln L_{it}	ln K_{it}	ln R_{it}
0	2.33 (.99)	3.46 (.99)	8.01 (.99)	9.45 (.99)
1	2.50 (.99)	-0.24 (.41)	8.43 (.99)	7.13 (.99)
2	10.36 (.99)	8.39 (.99)	10.27 (.99)	14.58 (.99)
3	15.22 (.99)	12.55 (.99)	11.63 (.99)	16.51 (.99)

Code:

`xtfisher lny, lags(1)` and

`pescadf lny, lags(1)` for each variable/lag-length or

`multipurt lny lnl lnk lnrd, lags(3)`

Table from: Eberhardt, Helmers & Strauss (*forthcoming*) ‘Do spillovers matter when estimating private returns to R&D?’, *The Review of Economics and Statistics*

1. Investigate share of variation explained by first two principal components.
2. Mean (absolute) correlation coefficients ($\hat{\rho}_{ij}, |\hat{\rho}_{ij}|$) of variables or residuals
3. Pesaran (2004) CD test
    - $$CD = \sqrt{\left(\frac{2}{N(N-1)}\right)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T_{ij}} \hat{\rho}_{ij}\right) \qquad CD \sim N(0,1)$$
    - `xtcsd` program only works after `xtreg`, quite limiting.
    - Can apply `xtcd` to test 'raw' variables, residuals of AR(2) regressions [pooled, heterog] and residuals from any other models.
4. Moscone and Tosetti (2009): number of alternative tests (but none perform better than CD).
5. Jensen & Schmitt (2011, *Spatial Econ Analysis*): Schott test of interest when N is small.
6. Variety of Spatial Econometric tests (cross-section) available if structure (W-matrix) is imposed.

Practical example

Panel A: Levels					Panel B: First Differences				
	$\ln Y_{it}$	$\ln L_{it}$	$\ln K_{it}$	$\ln R_{it}$		$\Delta\ln Y_{it}$	$\Delta\ln L_{it}$	$\Delta\ln K_{it}$	$\Delta\ln R_{it}$
avg ρ	0.29	0.30	0.55	0.40	avg ρ	0.17	0.17	0.20	0.03
avg $\lvert\rho\rvert$	0.59	0.57	0.77	0.78	avg $\lvert\rho\rvert$	0.26	0.28	0.34	0.34
CD	110.44	105.45	199.00	149.64	CD	58.78	59.08	68.53	12.50
p-value	0.00	0.00	0.00	0.00	p-value	0.00	0.00	0.00	0.00
Panel C: Pooled AR(2)					Panel D: Country-industry AR(2)				
	$\ln Y_{it}$	$\ln L_{it}$	$\ln K_{it}$	$\ln R_{it}$		$\ln Y_{it}$	$\ln L_{it}$	$\ln K_{it}$	$\ln R_{it}$
avg ρ	0.00	0.00	0.00	0.02	avg ρ	0.13	0.12	0.09	0.02
avg $\lvert\rho\rvert$	0.23	0.26	0.24	0.25	avg $\lvert\rho\rvert$	0.25	0.25	0.25	0.23
CD	-0.55	-1.42	-1.03	7.05	CD	45.46	42.20	33.78	8.44
p-value	0.58	0.16	0.30	0.00	p-value	0.00	0.00	0.00	0.00

Code:

`xtcd lny lnl lnk lnrd` (Panel A)

Table from: Eberhardt, Helmers & Strauss (*forthcoming*) ‘Do spillovers matter when estimating private returns to R&D?’, *The Review of Economics and Statistics*

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Some issues of testing for cointegration

Conceptual concerns

- In ***time-series***
    1. What's the ***null***: cointegration or noncointegration?
    2. Do we use a parametric (lags) or nonparametric (kernels) method to adjust for ***serial correlation in the residuals***?
- In ***panels*** we additionally need to worry about
    1. How much ***heterogeneity*** do we allow across groups/countries?
    2. How do we ***combine the statistics*** we arrive at if we opted for heterogeneous tests?

Major approaches

- Run some regression, collect residuals and test for stationarity ('residual-based tests')
- Construct an error correction model and investigate whether the EC term is significant ('error correction tests')

Cases to consider (leaving factors aside)

$$\begin{aligned} y_{it} &= \alpha_i + \beta_i x_{it} + u_{it} \\ x_{it} &= \mu + x_{i,t-1} + v_{it} \\ u_{it} &= \rho_i u_{i,t-1} + \varepsilon_{it} \end{aligned} \tag{2}$$

1. $\rho_i = 1 \; \forall \; i$, errors I(1), *no cointegration between x and y*,
2. $\rho_i < 1 \; \forall \; i$, errors stationary, *cointegration*,
3. $\rho_i < 1 \; \forall \; i$ and $\beta_i = \beta$; *homogeneous cointegration*, otherwise *heterogeneous cointegration.*
4. if there is *heterogeneous cointegration* but we impose homogeneity $\beta_i = \beta$ then what is in effect estimated is

   $$y_{it} = a_i + b x_{it} + \{(\beta_i - b) x_{it} + e_{it}\}$$

   where the composite error term in {} will generally <u>not</u> be stationary even though every group individually cointegrates

1st generation tests

- **Kao (1999)** — run a static fixed effects model of variables assumed cointegrated, get residuals and apply a pooled ADF regression (analogous to the Engle-Granger procedure in time-series). We get a Dickey-Fuller test of cointegration (if $\hat{e}_{it} \sim I(1)$ cannot reject H_0 of no cointegration, if $\hat{e}_{it} \sim I(0)$ reject H_0). Kao suggests a total of 5 tests, all rather restrictive on cointegrating vector (common) and dynamics (common).
- **Pedroni (1999)** and **Pedroni (2004)** — introduces flexibility/heterogeneity in terms of cointegrating vector and dynamics. Still residual tests in the Engle-Granger tradition. Two groups of statistics: 'group-mean' (heterog), 'panel' (pooled). Separate tests for parametric/ nonparametric versions. Adjustment terms to make all nine tests N(0,1) under null of no cointegration.
- **McCoskey and Kao (1998)** — LM test for H_0 of cointegration: reverse null test (like KPSS in stationarity testing). Distribution is non-standard: bootstrap.
- How does rejection of H_0 (no cointegration) come about in heterog tests? What's the **intuition**? Baltagi (2005, p.255): "enough of the individual cross-sections have statistics 'far away' from the means predicted by theory were they to be generated under the null."

None of these is coded in `Stata`, but Kao (1999) could be easily implemented.

2nd generation — Westerlund (2007)

ECM approach — check whether an ECM does/does not have error correction (individual group or full panel).

$$\Delta y_{it} = c_i + a_{0i}\left(y_{i,t-1} - b_i x_{i,t-1}\right) + \sum_{j=1}^{K_{1i}} a_{1ij}\Delta y_{i,t-j} + \sum_{j=-K_{2i}}^{K_{3i}} a_{2ij}\Delta x_{i,t-j} + u_{it} \qquad (3)$$

where a_{0i} is the error correction/speed of adjustment term. Note that penultimate term includes lags and leads of Δx, otherwise need to assume exogeneity of x. Estimate separately $\forall\, i$ (appropriate K_i). If $a_{0i} = 0 \rightarrow$ no error-correction $\rightarrow y, x$ not cointegrated. $a_{0i} < 0 \rightarrow$ EC → cointegration. In total 4 tests, based on 'group mean', 'pooled panel' idea. Large negative values reject H_0 of no cointegration. If ***CSD*** is suspected: use bootstrap to obtain robust critical values.

In practice: long T is important, strong assumption about the direction of causation from x to y (weak exogeneity of x).

Coded in `Stata` as `xtwest` (needs `matvsort`), often quite stark results (homog/heterog) unless T is large.

2nd generation — Gengenbach, Urbain, and Westerlund (2009)

Again: ECM approach. This time we assume a common factor structure for CSD and account for them in the test regressions

$$\begin{aligned}\Delta Y_{it} &= \alpha_i Y_{i,t-1} + \gamma_{1i} X_{i,t-1} + \gamma_{2i} F_{i,t-1} \\ &\quad + \sum_{s=1}^{p_i} \pi_{1is} \Delta Y_{i,t-s} + \sum_{s=0}^{p_i} \pi_{2is} \Delta X_{i,t-s} + \sum_{s=0}^{p_i} \pi_{3is} \Delta F_{i,t-s} + \varepsilon_{it} \qquad (4) \\ &= \alpha_i Y_{i,t-1} + \gamma_{1i} X_{i,t-1} + \psi_{1i} \bar{Y}_{t-1} + \psi_{2i} \bar{X}_{t-1} \\ &\quad + \sum_{s=1}^{p_i} \pi_{1is} \Delta Y_{i,t-s} + \sum_{s=0}^{p_i} \pi_{2is} \Delta X_{i,t-s} + \sum_{s=1}^{p_i} \phi_{1is} \Delta \bar{Y}_{t-s} + \sum_{s=0}^{p_i} \phi_{1is} \Delta \bar{X}_{t-s} + \varepsilon_{it} \qquad (5)\end{aligned}$$

Equation is estimated $\forall\, i$ individually with 'ideal' lag-length (AIC, BIC selection criterion), then results are averaged from either t-ratios of $\hat{\alpha}_i$ or a Wald test of $\hat{\alpha}_i$ and $\hat{\gamma}_{1i}$. Tests distributions are nonstandard, so we have to go by the values created from simulations. In practice apply a truncation rule to wipe out the influence of outliers.

With a little effort this can be coded in `Stata` — all you're doing is running country-regressions. I am currently working on this command: `xtectest`.

Empirical setup: common factor model

For $i = 1, \dots, N$, $t = 1, \dots, T$, let

$$\begin{aligned} y_{it} &= \boldsymbol{\beta}_i' \boldsymbol{x}_{it} + u_{it} \qquad u_{it} = \alpha_i + \boldsymbol{\gamma}_i' \boldsymbol{f}_t + \varepsilon_{it} \\ x_{mit} &= \pi_{mi} + \boldsymbol{\delta}_{mi}' \boldsymbol{g}_{mt} + \rho_{1mi} f_{1mt} + \ldots + \rho_{nmi} f_{nmt} + v_{mit} \\ & \text{where} \qquad m = 1, \dots, k \qquad \text{and} \qquad \boldsymbol{f}_{\cdot mt} \subset \boldsymbol{f}_t \end{aligned}$$

- CD-Production: observed output y_{it}, k observed factor inputs $\boldsymbol{x}_{it}$ (in logs).
- Unobserved common factors $\boldsymbol{f}_t$ (account for TFP) and $\boldsymbol{g}_t$.
- y_{it}, $\boldsymbol{x}_{it}$ as well as $\boldsymbol{f}_t, \boldsymbol{g}_{mt}$ are potentially nonstationary.
- Country-specific factor parameters $\boldsymbol{\beta}_i$.
- Country-specific factor loadings $\boldsymbol{\gamma}_i, \boldsymbol{\delta}_i, \boldsymbol{\rho}_i$.
- Country-specific fixed effects α_i, π_{mi}.
- i.i.d. errors ε_{it}, v_{it}.
- Correlation between u and x: endogeneity.

Empirical implementation

	Factor loadings:	
Technology parameters:	homogeneous	heterogeneous
homogeneous	A	B
heterogeneous	C	D

A — POLS, FE, FD-OLS (all with time dummies)
B — CCEP
C — MG, RCM (all with country trends)
D — CMG, AMG, ARCM

AMG is the 'Augmented Mean Group' estimator (Eberhardt & Teal, 2010), a two-step procedure conceptually similar to the Pesaran (2006) CCE estimator in the Mean Group version.

$$\text{(i)} \qquad \Delta y_{it} = \boldsymbol{b}' \Delta \boldsymbol{x}_{it} + \sum_{t=2}^{T} c_t \Delta D_t + e_{it} \;\; \Rightarrow \hat{\boldsymbol{c}}_t \equiv \hat{\mu}^{\bullet}_t$$

$$\text{(ii)} \qquad y_{it} = a_i + \boldsymbol{b}_i' \boldsymbol{x}_{it} + c_i t + d_i \hat{\mu}^{\bullet}_t + e_{it} \;\; \Rightarrow \hat{\boldsymbol{b}}_{AMG} = N^{-1} \sum_i \hat{\boldsymbol{b}}_i$$

Standard Mean Group (MG) estimator

N Time-series regressions: $y_{it} = a_i + \boldsymbol{b}_i'\boldsymbol{x}_{it} + c_i t + e_{it}$

Averaging: $\hat{\boldsymbol{b}}_{MG} = N^{-1}\sum_i \hat{\boldsymbol{b}}_i$

Common Correlated Effects Mean Group (CCEMG or CMG)

Major Insight: $\boldsymbol{f}_t = \bar{\boldsymbol{\gamma}}^{-1}(\bar{y}_t - \bar{\alpha} - \bar{\boldsymbol{\beta}}'\bar{\boldsymbol{x}}_t)$ for $N \to \infty$ since $\bar{\varepsilon}_t = 0$ (iff $\bar{\boldsymbol{\gamma}} \neq 0$)

Augmentation: $y_{it} = a_i + \boldsymbol{b}_i'\boldsymbol{x}_{it} + d_{1i}\bar{y}_t + \boldsymbol{d}_{2i}'\bar{\boldsymbol{x}}_t + e_{it}$

$\Rightarrow \hat{\boldsymbol{b}}_{CMG} = N^{-1}\sum_i \hat{\boldsymbol{b}}_i$ [can apply weights]

where the cross-section means $\bar{y}_t$ ($T \times 1$) and $\bar{\boldsymbol{x}}_t$ ($T \times k$) proxy for $\boldsymbol{f}_t$.
Incredibly simple setup, very powerful in ‘soaking up’ heterogeneities (observed, unobserved)

Common Correlated Effects Mean Pooled (CCEP)

Augmentation: $y_{it} = a_i + \boldsymbol{b}\boldsymbol{x}_{it} + d_{1i}\bar{y}_t + \boldsymbol{d}_{2i}'\bar{\boldsymbol{x}}_t + e_{it}$

Practical example: how to loose friends and alienate people…
…by rejecting not one but two empirical literatures/traditions:

- The **returns to R&D investment**. Why interesting? R&D is one of the few variables public policy can affect. Modern growth models: development through innovation. Empirical model:

$$y_{it} = \alpha l_{it} + \beta k_{it} + \gamma r_{it} + \lambda_t + \psi_i + e_{it} \tag{6}$$

- **R&D spillovers**. Trying to show if and how much 'knowledge spillovers' get created by R&D investment:

$$\begin{aligned} \mathrm{tfp}_{it} &= \psi_i + \gamma r_{it} + \chi \sum_{k=1}^{N} \omega_k r_{kt} + \varepsilon_{it} && (7) \\ y_{it} &= \alpha l_{it} + \beta k_{it} + \gamma r_{it} + \chi \sum_{k=1}^{N} \omega_k r_{kt} + \lambda_t + \psi_i + e_{it} && (8) \end{aligned}$$

Taken from: Eberhardt, Helmers & Strauss (*forthcoming*) 'Do spillovers matter when estimating private returns to R&D?', *The Review of Economics and Statistics*

Practical example

Estimator	POLS [1]	2FE [2]	MG [3]	CDMG [4]	CMG [5]	CMG [6]
$\ln L_{it}$	0.464	0.608	0.568	0.557	0.599	0.698
	[40.72]**	[18.41]**	[6.57]**	[7.63]**	[9.00]**	[8.24]**
$\ln K_{it}$	0.465	0.487	0.117	0.445	0.244	0.149
	[37.59]**	[10.60]**	[0.96]	[5.01]**	[1.70]	[1.00]
$\ln R_{it}$	0.096	0.063	-0.058	0.089	0.035	-0.050
	[22.80]**	[4.42]**	[0.73]	[2.12]*	[0.44]	[0.60]
dummies/trends	included	implicit	included			included
CRS	0.00	0.34	0.00	0.09	0.47	0.28
Order of integration	I(1)	I(1)	I(1)/I(0)	I(1)/I(0)	I(0)	I(1)/I(0)
CD Test	0.12	0.14	0.00	0.05	0.51	0.35
RMSE	0.278	0.163	0.051	0.068	0.037	0.035

2,637 observations, 119 country-sectors.

Code:

`xtmg lny lnl lnk lnrd, trend res(r_mg)` ([3])

`xtmg lny lnl lnk lnrd, cce res(r_cmg)` ([5])

`xtmg lny lnl lnk lnrd, cce trend res(r_cmg)` ([6])

Practicalities

Easy to implement CCEP estimator with existing `xtreg` command (single covariate example):

1. Create cross-section averages: `sort year`, then `by year:  egen lyT=mean(ly)`
2. `xi:  xtreg ly lx i.id|lyT i.id|lxT, fe` where id is the id variable for the cross-section (N) dimension.
3. Standard errors are wrong, so would need to apply the bootstrap or write a routine to correct them.

Pesaran, Shin, and Smith (1999) Pooled Mean Group (PMG)

Sometimes assuming a **common long-run equilibrium relationship** makes a lot of sense (e.g. in OECD countries):

$$\Delta y_{it} = \alpha_i + \beta_i \Delta x_{it} + \lambda_i(\theta x_{i,t-1} - y_{i,t-1}) + u_{it} \qquad u_{it} \sim iidN(0, \sigma_i^2) \tag{9}$$

β_i, are short-run parameters, which like σ_i^2 differ across countries.
Error-correction term λ_i also differs across i, long-run parameter θ however is *constant* across the groups. This estimators is quite appealing when studying small sets of arguably 'similar' countries rather than large diverse macro panels.

In I(1) panels this estimator allows for mix of cointegration ($\lambda_i > 0$) and noncointegration ($\lambda_i = 0$).

Code: `xtpmg d.lny d.lnx, lr(l.lny l.lnx) ec(ec) replace`.

The short-run equations can also be manually augmented with cross-section averages to yield the Binder and Offermanns (2007) C-PMG.

Work in Progress and Plans

- Pesaran et al. (2009) **CIPSM** PURT (`xtcipsm`)
- Gengenbach, Palm, and Urbain (2010) **EC** test of cointegration (`xtectest`)

When people find my website through google searches the most popular panel time series-related keywords relate to

- **PANIC**: Bai and Ng (2002, 2004) methods related to estimating the unobserved common factors.
- **GM-FMOLS**: Pedroni (2000) averaged FMOLS estimator.
- Pedroni's 7 panel **cointegration** tests (assuming cross-section independence)
- **CUP-FM**: Bai and Kao (2006) estimator.

Thank you.

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http://sites.google.com/site/medevecon (code, data),
http://twitter.com/sjoh2052 (data updates)

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