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Too much or too little?
New tools for the static CCE Estimator.

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https://janditzen.github.io/xtdcce2/

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Motivation I

- In panel time series models with $(N, T) \Rightarrow \infty$ cross-section dependence via unobserved common factors (or heterogeneity) is likely to occur.
- Often modelled using interactive fixed effects

$$y_{i,t} = \beta_i x_{i,t} + u_{i,t} \tag{1}$$
$$u_{i,t} = \gamma_{1,i} f_{1,t} + ... + \gamma_{M,i} f_{M,t} + \vartheta_{i,t} \tag{2}$$

- where we have M interactions between unit specific effects and time effects.
- $\gamma_{m,i}$ is the factor loading of factor $f_{m,t}$.

Motivation II

- The explanatory variables can also consist of a factor structure:

$$x_{i,t} = \gamma_{x,1,i} f_{x,1,t} + ... + \gamma_{M_x,i} f_{M_x,t} + \epsilon_{i,t}$$

- Assumption: $corr(\vartheta_{i,t}, \epsilon_{i,t}) = 0!$
- This setting poses two challenges:
  1. Correlation across units, cross-sectional dependence
  2. If the factors in $x_{i,t}$ and $u_{i,t}$ overlap, the observables and unobservables are correlated
- Popular estimator: Common Correlated Effects Estimator (Pesaran, 2006)

(Static) Common Correlated Effects

- Pesaran (2006) proposes to span the space of the common factors using cross-section averages (CSA) in a static model:

$$y_{i,t} = \beta_i x_{i,t} + \psi_{x,i}\bar{x}_t + \psi_{y,i}\bar{y}_t + \epsilon_{i,t}$$

  where $\bar{x}_t = 1/N \sum_{i=1}^{N} x_{i,t}$ and $\bar{y}_t = 1/N \sum_{i=1}^{N} y_{i,t}$ are the cross-section averages.
- Can be combined with a pooled or mean group estimator.
- Estimator is $\sqrt{N}$ consistent.
- Proved to be versatile in many conditions (Kapetanios et al., 2011; Chudik et al., 2011; Westerlund, 2018).
- Extended to dynamic models (Chudik and Pesaran, 2015) and estimation of long run coefficients (Chudik et al., 2016).

Static CCE

Stata Implementations

- First implementation in `xtmg` (Eberhardt, 2012).
- Also implemented in `xtdcce2` (Ditzen, 2018a, 2021):
  - Static and dynamic models
  - Estimation of long run coefficients
  - Bootstrapping
  - Different types of cross-section averages
  - Estimation of degree and testing for cross-section dependence
  - Various `estat` and `predict` functions
- Syntax:

  `xtdcce2` *depvar indepvars* [*if*] , ... *cr(varlist , options)*

  - `cr()` defines variables added as cross-section averages.

Static CCE

New developments

- In "early" years discussion on CCE focused on validity under stationary factors, autocorrelated factors, strong and semi strong cross-section dependence and dynamic models.
- A recurring topic is also bootstrapping.
- In past years discussion on what "spanning factor space" actually means intensified:
  1. Regularized CCE
  2. When does the "Rank Condition" hold?
  3. Information Criteria to select CSA.

Regularized CCE

- Large number of cross-section averages might only contain limited information, inducing non-trivial bias for pooled and mean group CCE, see Karabiyik et al. (2017).
- Juodis (2022) suggest rCCE approach:
  - Calculate cross-section averages (CSA)
  - Estimate number of common factors in CSA, $\hat{m}$, using ER or GR from Ahn and Horenstein (2013)
  - Replace cross-section averages with the first $\hat{m}$ eigenvectors of CSA.
- Requires bootstrapping.
- Disadvantage: approach sensitive to estimation of factors and only for static panels.

Regularized CCE

`xtdcce2, ... cr(rcce)`

`xtdcce2` *depvar indepvars* [*if*] , ... *cr(varlist , rcce[(options)])*

- `options` are:
  - `criterion(er|gr)` specifies criterion to estimate number of common factors using the ER or GR criterion from Ahn and Horenstein (2013)
  - `scale` scales cross-section averages
  - `npc(real)` specifies number of eigenvectors without estimating it.
- Bootstrap is not automatically performed.
- Number of factors estimated based on `xtnumfac` (Ditzen and Reese, 2023).
- Unbalanced panels supported, then missing values in CSA are imputed.

Regularized CCE

Example

- Dell et al. (2012) investigate effect of temperature ($wtem_{i,t}$) and precipitation ($wpre_{i,t}$) on economic growth ($g_{i,t}$).
- Balanced panel of 89 countries and over 42 years (1962-2003):[1]

$$g_{i,t} = \mu_i + \beta_{1,i} wtem_{i,t} + \beta_{2,i} wpre_{i,t} + u_{i,t}$$

- Estimated number of common factors (output shortened):

```
. xtnumfac g wtem wpre , stand(5)
 N    =      3738                     T      =       42
 N_g =        89                      vars.  =        3
------------------------------------------------------------
 IC          |  # factors   |  IC        |  # factors
------------------------------------------------------------
...
 ER          |      1       |  GR        |      1
...
------------------------------------------------------------
8 factors maximally considered.
...
ER, GR from Ahn and Horenstein (2013)
...
```

[1] This is only an example!

Regularized CCE

Example MG (no CSA)

```
. xtdcce2 g wtem wpre, cr(g wtem wpre)
(Dynamic) Common Correlated Effects Estimator - Mean Group

Panel Variable (i): cc_num                      Number of obs       =      3738
Time Variable (t): year                         Number of groups    =        89

Degrees of freedom per group:                   Obs per group (T)   =        42
 without cross-sectional averages   = 39
 with cross-sectional averages      = 36
Number of                                       F(534, 3204)        =      0.40
 cross-sectional lags               0 to 0      Prob > F            =      1.00
 variables in mean group regression = 178       R-squared           =      0.94
 variables partialled out           = 356       R-squared (MG)      =      0.10
                                                Root MSE            =      5.04
                                                CD Statistic        =      0.79
                                                   p-value          =    0.4322
-------------------------------------------------------------------------------
           g|     Coef.    Std. Err.       z     P>|z|     [95% Conf. Interval]
------------+------------------------------------------------------------------
 Mean Group:|
        wtem| -.4927157    .3991215    -1.23    0.217     -1.27498     .289548
        wpre|  .0794224    .0863427     0.92    0.358    -.0898062     .248651
-------------------------------------------------------------------------------
Mean Group Variables: wtem wpre
Cross Sectional Averaged Variables: g wtem wpre
Heterogenous constant partialled out.
```

- `cr(g wtem wprec)` adds cross-section averages of g, wtem and wprec.
- No strong cross-section dependence left in residuals.
- No coefficients significant.
- Space of one common factor spanned by 3 cross-section averages.

Regularized CCE

Example

```
. xtdcce2 g wtem wpre, cr(g wtem wpre, rcce(npc(1)))
(Dynamic) Common Correlated Effects Estimator - Mean Group
Panel Variable (i): cc_num                        Number of obs      =      3738
Time Variable (t): year                           Number of groups   =        89
Degrees of freedom per group:                     Obs per group (T) =        42
 without cross-sectional averages     = 39
 with cross-sectional averages        = 36
Number of                                         F(534, 3204)       =      0.44
 cross-sectional lags                 = 0         Prob > F           =      1.00
 variables in mean group regression = 178         R-squared          =      0.93
 variables partialled out             = 356       R-squared (MG)     =     -0.04
                                                  Root MSE           =      5.43
                                                  CD Statistic       =     18.31
                                                     p-value         =    0.0000
---------------------------------------------------------------------------------
            g |     Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+------------------------------------------------------------------
 Mean Group:  |
         wtem | -.8734512   .2471953    -3.53   0.000     -1.357945   -.3889572
         wpre |  .1390204   .0975042     1.43   0.154     -.0520843    .3301251
---------------------------------------------------------------------------------
Mean Group Variables: wtem wpre
1 Regularized Cross-Section Averages from variables:
 g wtem wpre
Heterogenous constant partialled out.
```

- `cr(... , rcce(npc(1))` employs rCCE estimator with 1st eigenvalue instead of CSA.
- Some strong cross-section dependence left in residuals.
- Temperature significant.
- `xtdcce2` can also estimate number of common factors in CSA Example.

Static CCE

The Rank Condition

- Key for consistent estimation is the rank condition.
- Rank condition implies that - loosely speaking(!!) - rank of average factor loadings has to be larger or equal than rank of factors.
- Karabiyik et al. (2017, 2021) show that if rank condition fails, CCE is inconsistent!
- Implies that adding CSAs with zero loadings, might lead to problems!
- In empirical practice: more CSA required than factors.

Rank Condition Classifier

- Reminder: Rank of unobserved factors (f), m, is not larger than the rank of unobserved average factor loadings (γ), g.
- Problem: both are unobserved! DeVos et al. (2024) propose a indicator if the rank conditions holds:

$$\widehat{RC} = 1 - I(\hat{g} < \hat{m}) \tag{3}$$

where $\hat{m}$ is the rank of the cross/product of the observed data estimated by ER or GR from Ahn and Horenstein (2013) and $\hat{g}$ is rank of the unobserved factor loadings estimated from cross-section averages.
- If $\widehat{RC} = 1$, rank condition holds.
- Requires bootstrap to estimate variance of rank estimator of factor loadings.
- Consistency depends on fixed T. Trick: bound dimension with shrinkage.
- Indicator only valid for static panels.

Rank Condition Classifier

`xtdcce2, ... cr(rccl)`

`xtdcce2` *depvar indepvars* [*if*] , ... *cr(varlist , rcclassifier[(options)])*

- `options` are:
  - `er|gr` specifies criterion to estimate number of common factors using the ER or GR criterion from Ahn and Horenstein (2013)
  - `standardize(integer)` standardize data prior to estimation of number of common factors.
  - `replications(integer)` sets number of replication for bootstrapping variance of the rank estimator of the unobserved matrix of average factor loadings.
  - `randomshrinkage` Instead of fold-over matrix, use matrix with entries drawn from random normal distribution.
  - `noshrinkage` No shrinkage.
- Number of factors estimated based on `xtnumfac` (Ditzen and Reese, 2023).

Rank Condition Classifier

Example

```
. xtdcce2 g wtem wpre, cr(g wtem wpre, rccl)
(Dynamic) Common Correlated Effects Estimator - Mean Group
Panel Variable (i): cc_num                        Number of obs      =      3738
Time Variable (t): year                           Number of groups   =        89
Degrees of freedom per group:                     Obs per group (T)  =        42
 without cross-sectional averages   = 39
 with cross-sectional averages      = 36
Number of                                         F(534, 3204)       =      0.40
 cross-sectional lags               0 to 0        Prob > F           =      1.00
 variables in mean group regression = 178         R-squared          =      0.94
 variables partialled out           = 356         R-squared (MG)     =      0.10
                                                  Root MSE           =      5.04
                                                  CD Statistic       =      0.79
                                                     p-value         =    0.4322
-------------------------------------------------------------------------------
             g|     Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
 Mean Group:  |
          wtem|  -.4927157   .3991215   -1.23   0.217     -1.27498    .289548
          wpre|   .0794224   .0863427    0.92   0.358    -.0898062    .248651
-------------------------------------------------------------------------------
Mean Group Variables: wtem wpre
Cross Sectional Averaged Variables: g wtem wpre
Heterogenous constant partialled out.
---------------------------------------------------------------------
Classifier for Rank Condition (De Vos, Everaert and Sarafidis, 2024)
---------------------------------------------------------------------
      RC      |   Estimated
 (1-I(g<m))*  |   Rank (g)   Number of Factors (m)
--------------+------------------------------------------------------
      1       |   2              1
---------------------------------------------------------------------
* RC=1 indicates rank condition holds. g is rank of matrix of cross-sectional averages, m is number of factors in the data.
```

- `cr(...  , rccl)` requests calculation or rank condition classifier.
- More common factors in CSA than in unobserved factors.

Information Criteria and CCE

- Long time no theory for use of information criteria and CCE
- Information criteria can be used for 2 purposes:
  - Selection of cross-section averages
  - Lag selection in dynamic models
- 1) received recently attention:
  - DeVos et al. (2024) propose a sequential method to identify the set of relevant cross-section averages.
  - Margaritella and Westerlund (2023) propose a similar criteria as in Bai and Ng (2002); Bai (2009).
- **No** guidance on **lag selection** in dynamic models - left for research!

Information Criteria and CCE

- Margaritella and Westerlund (2023) propose 4 criteria to identify the optimal set of cross-section averages:

$$IC_1(M) = ln\hat{\sigma}^2\left(\hat{F}_M\right) + m\frac{N+T}{NT}ln\left(\frac{NT}{N+T}\right), \qquad IC_2(M) = ln\hat{\sigma}^2\left(\hat{F}_M\right) + m\frac{N+T}{NT}ln\left(C_{NT}^2\right)$$

$$PC_1(M) = \hat{\sigma}^2\left(\hat{F}_M\right) + m\hat{\sigma}^2\left(\hat{F}_{\bar{M}}\right)\frac{N+T}{NT}ln\left(\frac{NT}{N+T}\right), \quad PC_2(M) = \hat{\sigma}^2\left(\hat{F}_M\right) + m\hat{\sigma}^2\left(\hat{F}_{\bar{M}}\right)\frac{N+T}{NT}ln\left(C_{NT}^2\right)$$

  with $\hat{\sigma}^2(\hat{F}_M)$ the error variance from a CCE estimation with m CSA and $\left(\hat{F}_{\bar{M}}\right)$ is the error variance with the full set of CSA.
- Optimal set of CSA is then $\hat{M} = argminIC(M)$.
- Integrated in `xtdcce2` as `estat ic`.
- Caveat: can only be applied to static models.

Information Criteria and CCE

Example

```
. estat ic
IC from Margaritella & Westerlund (2023)
```

Model	IC1	IC2	PC1	PC2
1	3.43*	3.48*	.	.

- ICs alone are not informative.
- Option `sequential` compares all permutations of CSA.

Information Criteria and CCE

Example

```
. estat ic, seq
Running 7 combinations of cross-section averages:
. . . . . . . .
IC from Margaritella & Westerlund (2023)
```

Model	IC1	IC2	PC1	PC2
1	3.34	3.35	28	28
2	3.34	3.35	28	28
3	3.25*	3.26*	25.8*	25.8*
4	3.43	3.45	29.7	29.7
5	3.34	3.36	27.9	27.9
6	3.34	3.37	27.6	27.6
7	3.43	3.48	29.7	29.7

```
 * indicates minimum.
 Cross Section Averages:
  Model 1: wpre
  Model 2: wtem
  Model 3: g
  Model 4: wtem wpre
  Model 5: g wpre
  Model 6: g wtem
  Model 7: g wtem wpre (Main Model)
 Click on Model to run in xtdcce2.
```

- Model with 3 CSA has lowest IC.
- Possible to run models directly in Stata.
- Many combinations possible which can take time.

Taming the tests for cross-section dependence zoo

- Pesaran (2015, 2021) proposes a test for weak cross-section dependence, the CD-test:

  H_0 weak dependence vs. H_1 strong dependence
- Test statistic:

$$CD = \sqrt{\frac{2T}{N(N-1))}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{i,j},$$

  with $\rho_{i,j}$ is the correlation coefficient.
- Under the null hypothesis asymptotically: $CD \sim N(0,1)$.
- In Stata: `xtcd2` (Ditzen, 2018b), `xtcd`, `xtcsd` (De Hoyos and Sarafidis, 2006), ...
- Problem of the CD test: tends to over reject.

Taming the tests for cross-section dependence zoo[2]

- Recent developments: CDw (Juodis and Reese, 2021), CDw with power enhancement (Fan et al., 2015) and CD* (Pesaran and Xie, 2021)
- CD* is complicated, but actually tests for independence against weak dependence in the presence of latent factors:

```
. xtcd2  g wtem wpre
Testing for cross-sectional dependence (CSD)
     CD CDw CDw+                            CD*
 H0: weak cross-section dependence      independence in presence of factors
 H1: strong cross-section dependence    weak dependence in presence of factors
```

	CD	CDw	CDw+	CD*
g	29.35	-0.66	3519.69	2.82
	(0.000)	(0.508)	(0.000)	(0.005)
wtem	149.24	-0.75	9856.16	5.08
	(0.000)	(0.452)	(0.000)	(0.000)
wpre	22.18	-1.09	4035.09	4.89
	(0.000)	(0.275)	(0.000)	(0.000)

```
p-values in parenthesis.
References
  CD:        Pesaran (2015, 2021)
  CDw:       Juodis, Reese (2021)
  CDw+:      CDw with power enhancement from Fan et al. (2015)
  CD*:       Pesaran, Xie (2021) with 4 PC(s)
```

[2] Beta version of `xtdcce2` 4.9. Results may change.

Summary

- New developments in the CCE literature on **static** models:
  - Regularized CCE (rCCE)
  - Rank condition classifier
  - Information criteria to select CSA
- rCCE available with `xtdcce2` version 4.0.
- Rank condition classifier and IC will be available with version 4.7.
- How to install?

```
net install xtdcce2 , from("https://janditzen.github.io/xtdcce2/")
```

- More info:

jan.ditzen.net

GitHub

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MG with no CSA back

```
. xtdcce2 g wtem wpre, nocross
(Dynamic) Common Correlated Effects Estimator - Mean Group

Panel Variable (i): cc_num                       Number of obs        =      3738
Time Variable (t): year                          Number of groups     =        89

Degrees of freedom per group:                    Obs per group (T)    =        42
 without cross-sectional averages    = 39
 with cross-sectional averages       = 39
Number of                                        F(267, 3471)         =      0.87
 cross-sectional lags                none        Prob > F             =      0.93
 variables in mean group regression = 178        R-squared            =      0.94
 variables partialled out           = 89         R-squared (MG)       =      0.01
                                                 Root MSE             =      5.28
                                                 CD Statistic         =     22.42
                                                    p-value           =    0.0000
------------------------------------------------------------------------------
           g|     Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------+-----------------------------------------------------------------
 Mean Group:|
        wtem| -.6109638   .2163648    -2.82   0.005    -1.035031   -.1868967
        wpre|  .1805911    .088414     2.04   0.041     .0073029    .3538793
------------------------------------------------------------------------------
Mean Group Variables: wtem wpre
Heterogenous constant partialled out.
```

rCCE - number of factors estimated back

```
. xtdcce2 g wtem wpre, cr(g wtem wpre, rcce)
(Dynamic) Common Correlated Effects Estimator - Mean Group

Panel Variable (i): cc_num                      Number of obs      =      3738
Time Variable (t): year                         Number of groups   =        89

Degrees of freedom per group:                   Obs per group (T) =        42
 without cross-sectional averages    = 39
 with cross-sectional averages       = 36
Number of                                       F(534, 3204)       =      0.47
 cross-sectional lags                = 0        Prob > F           =      1.00
 variables in mean group regression = 178       R-squared          =      0.93
 variables partialled out            = 356      R-squared (MG)     =      0.07
                                                Root MSE           =      5.11
                                                CD Statistic       =      0.43
                                                   p-value         =    0.6704
-------------------------------------------------------------------------------
             g|      Coef.   Std. Err.       z    P>|z|     [95% Conf. Interval]
-------------------------------------------------------------------------------
 Mean Group:  |
          wtem| -.0618716   .3554096   -0.17    0.862     -.7584617   .6347185
          wpre|  .1070671   .0918071    1.17    0.244     -.0728715   .2870057
-------------------------------------------------------------------------------
Mean Group Variables: wtem wpre
2 Regularized Cross-Section Averages from variables:
 g wtem wpre
Heterogenous constant partialled out.
```

Information Criteria and CCE

Example

```
. estat ic, model((g wtem wpre) (g) (g wtem))
Running 3 combinations of cross-section averages:
. . .
IC from Margaritella & Westerlund (2023)
```

Model	IC1	IC2	PC1	PC2
1	3.43	3.48	29.5	29.5
2	3.25*	3.26*	25.4*	25.4*
3	3.34	3.37	27.7	27.7

```
* indicates minimum.
Cross Section Averages:
 Model 1: g wtem wpre (Main Model)
 Model 2: g
 Model 3: g wtem
Click on Model to run in xtdcce2.
```

- Compare specific models.
- Syntax: `model( (model1) (model2) ... ).`
- `(model1)` is the reference model.

Static CCE

Mean Group Estimator

- Main contributions: Pesaran and Smith (1995); Pesaran (2006); Chudik and Pesaran (2019)
- $\hat{\beta}_{MG} = \frac{1}{N}\sum_{i=1}^{N}\hat{\beta}_i$
- Asymptotic variance estimator $V(\hat{\beta}_{MG}) = \frac{1}{N(N-1)}\sum_{i=1}^{N}\left(\hat{\beta}_i - \hat{\beta}_{MG}\right)^2$
- Individual coefficients asymptotically normal with $(N,T)\xrightarrow{j}\infty$ with no particular order. Rank condition requires $\sqrt{T}/N \to 0$.
- Mean group asymptotically unbiased if $N \to \infty$ and T fixed and $(N,T)\xrightarrow{j}\infty$. Also needs $T > K$.

Static CCE

Pooled Estimator

- Main contribution: Pesaran (2006)
- Estimate β_p directly with the condition $\beta_i = \beta_p$.
- Various variance estimators, such as $V(\hat{\beta}_p)_{np} = f(\hat{\beta}_i, \hat{\beta}_{MG}, \tilde{X}'\tilde{X})$ or $V(\hat{\beta}_p)_{hac} = f(\hat{\beta}_p, \tilde{X}'\tilde{X}, \hat{\epsilon}_{i,t})$.
- Depending on the estimator, we need to make sure that the residuals are cross-section dependence free!
- Asymptotically normal with $(N, T) \xrightarrow{j} \infty$ with no particular order.