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ECONOMETRICS
Panel Data Models

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Panel Data Models

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- Panel data models
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Panel data models

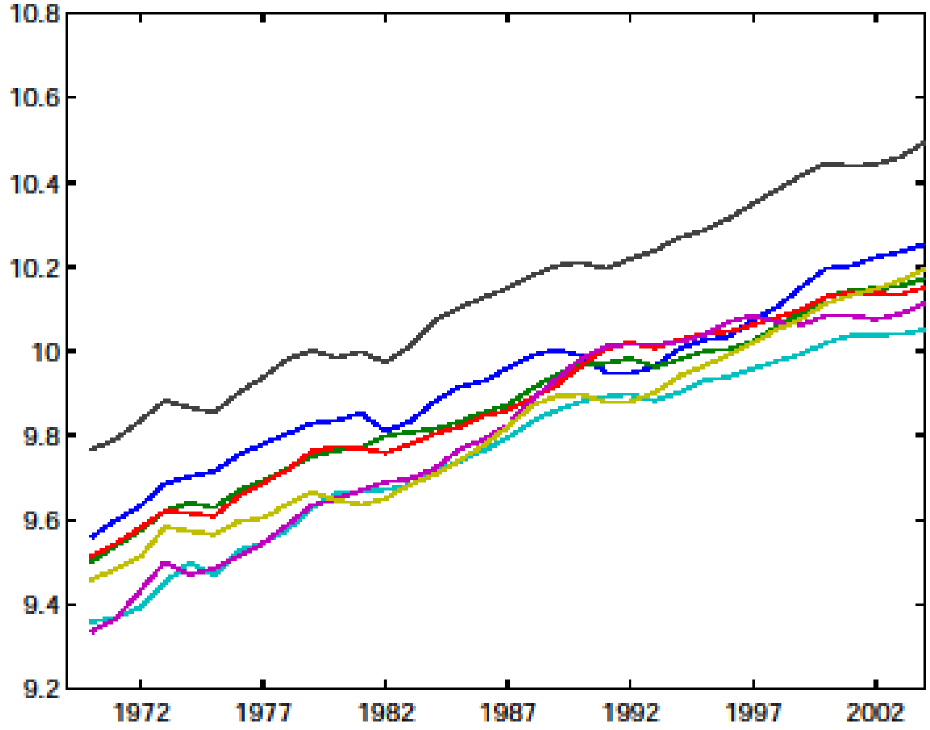
Introduction and motivation

Advantages:

- Larger number of data points (more degrees of freedom)
- Combine cross section and time series data
- Limitation of the omitted variable problem
- Takes into account common and cross sectional explanatory variables
- May account for cross sectional dependence

Panel data

GDP series for the G7 countries



Panel data

Dependent variables and Specific cross sectional explanatory variables

- **Panel data:**

  Dependent variable: Y_{it}, $i = 1, \dots, N$ $(cross\ section\ unit)$
  $t = 1, \dots, T$ $(time\ period)$

  Explanatory variables (specific cross sectional unit variables, i.e. different for each unit)

  X_{ijt}, $i = 1, \dots, N$ $(cross\ section\ unit)$
  $j = 1, \dots, k$ $(explanatory\ variables)$
  $t = 1, \dots, T$ $(time\ period)$

  E.g.: Y_{it}: GDP for different countries across time, X_{ijt}: investments, industrial production, unemployment for different countries across time

Y1	Y2	…	YN	X11	X12	…	X1k	…	XN1	XN2	…	XNk
Y_{11}	Y_{21}	…	Y_{N1}	X_{111}	X_{121}	…	X_{1k1}	…	X_{N11}	X_{N21}	…	X_{Nk1}
Y_{12}	Y_{22}	…	Y_{N2}	X_{112}	X_{122}	…	X_{1k2}	…	X_{N12}	X_{N22}	…	X_{Nk2}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	…	$\vdots$	$\vdots$	$\ddots$	$\vdots$
Y_{1T}	Y_{2T}	…	Y_{NT}	X_{11T}	X_{12T}	…	X_{1kT}	…	X_{N1T}	X_{N2T}	…	X_{NkT}

Panel data

Dependent variables and Common explanatory variables

- **Panel data:**

  Dependent variable: $Y_{it}, \quad i = 1, \dots, N \ (cross\ section\ unit)$
  $t = 1, \dots, T \ (time\ period)$

  Explanatory variables (common variables, i.e. common for each unit)

  $X_{jt}, \quad j = 1, \dots, k \ (explanatory\ variables)$
  $t = 1, \dots, T \ (time\ period)$

  E.g.: Y_{it}: GDP for different countries across time, X_{jt}: global volatility index, global panic index across time (common explanatory variables for all units)

Y1	Y2	…	YN
Y_{11}	Y_{21}	…	Y_{N1}
Y_{12}	Y_{22}	…	Y_{N2}
$\vdots$	$\vdots$	$\ddots$	$\vdots$
Y_{1T}	Y_{2T}	…	Y_{NT}

X1	X2	…	Xk
X_{11}	X_{21}	…	X_{k1}
X_{12}	X_{22}	…	X_{k2}
$\vdots$	$\vdots$	$\ddots$	$\vdots$
X_{1T}	X_{2T}	…	X_{kT}

Panel data models

A general dynamic panel data model

- Consider the following dynamic panel data model:

$$Y_{it} = \delta_i + \beta_i t + \sum_{k=1}^{K} \alpha_{ik} X_{kt} + \sum_{q=1}^{Q} \gamma_{iq} X_{iqt} + \varepsilon_{it},$$
$$\varepsilon_{it} = \varphi_i \varepsilon_{i,t-1} + u_{it},$$

where

- $i = 1, \dots, N$ denotes the cross-sectional units of the panel (e.g. countries)
- $t = 1, \dots, T$ denotes the time period
- Y_{it} denotes the economic or financial dependent variable (e.g. gross domestic product)
- X_{kt} is a set of K exogenous explanatory factors or covariates (e.g. a global volatility index, a market or a commodity index) which are common for all cross-sectional units of the panel, and affect the dependent variables of the panel through separate/different coefficients α_{ik}
- X_{iqt} is a set of Q of cross-sectional specific factors (explanatory variables) which are different for each cross-sectional unit with separate coefficients γ_{iq}
- δ_i are the intercept coefficients of the model, which are different for each cross sectional unit
- β_i are the trend coefficients, which are different for each cross sectional unit
- ε_{it} is a zero-mean autoregressive one, AR(1), process which captures the dynamics of the panel data model. The error term u_{it} is assumed not to be serially correlated, i.e. $E(u_{is}u_{it}) = 0$, for all $t \neq s$ and for all i, but it is heterogeneous and correlated across i, i.e. $E(u_{it}u_{jt}) \neq 0$ for all i and j, and therefore, allows for cross sectional dependence across units

Panel data models

Basic linear panel data model

- The **basic linear panel data model** used in econometric literature can be described through suitable restrictions of the following general model:

$$Y_{it} = \alpha_{it} + \beta_{it} X_{it} + u_{it},$$

where

- $i = 1, \dots, N$ denotes the cross-sectional units of the panel
- $t = 1, \dots, T$ denotes the time period
- Y_{it} denotes the economic or financial dependent variable
- X_{it} is the explanatory factors or covariates
- α_{it} is the intercept, which is different for each cross sectional unit, and across time
- β_{it} are the explanatory variables coefficients, which are different for each cross sectional unit, and across time
- u_{it} is the error term

- Number of observations: NT
- Number of parameters to be estimated: 2NT
- Can not be estimated !! Thus, **suitable restrictions are imposed** on α_{it} and β_{it}

Panel data models

A simple panel data model (model I)

- The simplest panel data model assumes parameter homogeneity. In the general linear panel model $\mathrm{Y}_{it} = \alpha_{it} + \beta_{it}\mathrm{X}_{it} + u_{it}$ impose the following restrictions: $\alpha_{it} = \alpha$ and $\beta_{it} = \beta$ for all i, t. The resulting model can be written in the form:

$$\mathrm{Y}_{it} = a + \beta\mathrm{X}_{it} + u_{it},$$

where

- $i = 1, \dots, N$ denotes the cross-sectional units of the panel
- $t = 1, \dots, T$ denotes the time period
- Y_{it} denotes the economic or financial dependent variable
- X_{it} is the explanatory factors or covariate
- a is the intercept of the model, which is common for all cross sectional units and across time
- β is the explanatory variable coefficient, which is common for all cross sectional units across time
- u_{it} is the error term

- This simple panel model does not account for the heterogeneity of the cross sectional units (common a and β parameter)
- Number of observations: NT
- Number of parameters to be estimated: 2

Panel data models

Fixed effects panel data model (model II)

- In the general linear panel data model $\mathrm{Y}_{it} = \alpha_{it} + \beta_{it}\mathrm{X}_{it} + u_{it}$ impose the following restrictions: $\alpha_{it} = \alpha_i$ for all t, and $\beta_{it} = \beta$ for all i and t. The resulting model is called the **fixed effects model**:

$$\mathrm{Y}_{it} = \alpha_i + \beta\mathrm{X}_{it} + u_{it},$$

where

- $i = 1, \dots, N$ denotes the cross-sectional units of the panel
- $t = 1, \dots, T$ denotes the time period
- Y_{it} denotes the economic or financial dependent variable
- X_{it} is the explanatory factors or covariate
- α_i is the intercept of the model, which is different for each cross sectional unit
- β is the slope, which is common for all cross sectional units
- u_{it} is the error term

- This panel model accounts for the heterogeneity of the cross sectional units (different intercept coefficients α_i, common β parameter)
- Number of observations: NT
- Number of parameters to be estimated: N+1

Panel data models

Fixed effects panel data model (model III)

- In the general linear panel data model $\mathrm{Y}_{it} = \alpha_{it} + \beta_{it}\mathrm{X}_{it} + u_{it}$ impose the following restrictions: $\alpha_{it} = \alpha_i$, and $\beta_{it} = \beta_i$ for all t. The resulting model is:

$$\mathrm{Y}_{it} = \alpha_i + \beta_i \mathrm{X}_{it} + u_{it},$$

- $i = 1, \dots, N$ denotes the cross-sectional units of the panel
- $t = 1, \dots, T$ denotes the time period
- Y_{it} denotes the economic or financial dependent variable
- X_{it} is the explanatory factors or covariate
- α_i is the intercept of the model, which is different for each cross sectional unit
- β_i is the slope, which is different for each cross sectional unit
- u_{it} is the error term

- This panel model accounts for the heterogeneity of the cross sectional units (different intercept coefficients α_i, and different β_i coefficients)
- Different parameters across units, but constant across time
- Number of observations: NT
- Number of parameters to be estimated: 2N
- To be able to estimate this model: T>2

Panel data models: Fixed Effects

Least Squares Dummy variables (LSDV)

- Consider the following fixed effects panel data model:

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it}$$

- Fixed parameters α_i (non stochastic), different for each sectional unit, common β
- We are interested in:
  - Estimate the model parameters
  - Perform hypothesis testing (for the heterogeneity of intercept parameters)
- Re-write the model by using/constructing appropriate dummy variables

$$\mathrm{Y}_{it} = \alpha + \beta \mathrm{X}_{it} + \gamma_2 d_{2t} + \gamma_3 d_{3t} + \cdots + \gamma_N d_{Nt} + u_{it}$$

- Number of observations: NT, number of parameters: $2 + (N - 1) = N + 1$

- The model implies that:

$i = 1$: $\mathrm{Y}_{1t} = \alpha + \beta \mathrm{X}_{1t} + u_{1t}$

$i = 2$: $Y_{2t} = \alpha + \beta \mathrm{X}_{2t} + \gamma_2 d_{2t} + u_{2t} \Rightarrow \mathrm{Y}_{2t} = (\alpha + \gamma_2) + \beta \mathrm{X}_{2t} + u_{2t}$

$i = 3$: $Y_{3t} = \alpha + \beta \mathrm{X}_{3t} + \gamma_3 d_{3t} + u_{3t} \Rightarrow \mathrm{Y}_{3t} = (\alpha + \gamma_3) + \beta \mathrm{X}_{3t} + u_{3t}$

$\vdots$

$i = N$: $Y_{Nt} = \alpha + \beta \mathrm{X}_{Nt} + \gamma_N d_{Nt} + u_{Nt} \Rightarrow \mathrm{Y}_{Nt} = (\alpha + \gamma_N) + \beta \mathrm{X}_{Nt} + u_{Nt}$

Panel data models: Fixed Effects

Construct the dummy variables

i	t	Y	X	D2	D3
1	1	Y_{11}	X_{11}	0	0
	2	Y_{12}	X_{12}	0	0
	⋮	⋮	⋮	⋮	⋮
	T	Y_{1T}	X_{1T}	0	0
2	1	Y_{21}	X_{21}	1	0
	2	Y_{22}	X_{22}	1	0
	⋮	⋮	⋮	⋮	⋮
	T	Y_{2T}	X_{2T}	1	0
3	1	Y_{31}	X_{31}	0	1
	2	Y_{32}	X_{32}	0	1
	⋮	⋮	⋮	⋮	⋮
	T	Y_{2T}	X_{3T}	0	1

Example: number of units $\mathrm{N} = 3$ (i.e. construct $N - 1 = 2$ dummy variables), time period T, dependent variable Y_{it}, explanatory variable X_{it}

Panel data models: Fixed Effects

Hypothesis testing (t-test)

- For the fixed effects panel data model of the form:

$$Y_{it} = \alpha + \beta X_{it} + \gamma_2 d_{2t} + \gamma_3 d_{3t} + \cdots + \gamma_N d_{Nt} + u_{it}$$

we can perform two types of hypothesis tests:

- **(i) t-test:**

$$H_0: \gamma_i = 0$$
$$H_1: \gamma_i \neq 0$$

by using the following test statistic:

$$T = \frac{\hat{\gamma}_i}{se(\hat{\gamma}_i)}$$

The hypothesis testing about parameters γ_i is very important, since if we reject the null hypothesis (H_0: $\gamma_i = 0$), this implies that parameter γ_i is statistically significant at level α, and the corresponding intercept parameter for unit i, is $\alpha + \gamma_i$, and is statistically different than the intercept (α) of the baseline cross sectional unit 1.

Panel data models: Fixed Effects

Hypothesis testing (F-test)

- **(ii) F-test:**
  $H_0: \gamma_2 = \gamma_3 = \cdots = \gamma_N = 0$
  $H_1: not\ H_0$
  The null hypothesis implies the following restricted model:
  $$H_0:\ Y_{it} = \alpha + \beta X_{it} + u_{it}$$
  while the alternative hypothesis implies the unrestricted model:
  $$H_1:\ Y_{it} = \alpha + \beta X_{it} + \gamma_2 d_{2t} + \gamma_3 d_{3t} + \cdots + \gamma_N d_{Nt} + u_{it}$$

- The F-test statistic can be used:
  $$F = \frac{(RSS_R - RSS_{Unr})/(df_R - df_{Unr})}{RSS_{Unr}/df_{Unr}} \sim F_{\mathrm{N-1,NT-N-1}}$$

- RSS_R and RSS_{Unr} are the residual sum of squares of the restricted and the unrestricted model, respectively

- $df_R = NT - 2$ and $df_{Unr} = NT - 2 - (N-1) = NT - N - 1$ are the degrees of freedom of the restricted and the unrestricted model, respectively, and $df_R - df_{Unr} = [NT-2] - [NT - N - 1] = N - 1$

Panel data models: Fixed Effects

Within Estimator

- Consider the following fixed effects panel data model:

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it} \quad (1)$$

- Define

$$\bar{Y}_i = \frac{1}{T}\sum_{t=1}^{T} \mathrm{Y}_{it}, \qquad \bar{X}_i = \frac{1}{T}\sum_{t=1}^{T} X_{it}, \qquad \bar{u}_i = \frac{1}{T}\sum_{t=1}^{T} u_{it}$$

- Then

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it} \Rightarrow$$

$$\Rightarrow \frac{1}{T}\sum_{t=1}^{T} \mathrm{Y}_{it} = \frac{1}{T}\sum_{t=1}^{T} \alpha_i + \frac{1}{T}\beta \sum_{t=1}^{T} \mathrm{X}_{it} + \frac{1}{T}\sum_{t=1}^{T} u_{it} \Rightarrow$$

$$\Rightarrow \bar{Y}_i = \frac{1}{T}\mathrm{T}\alpha_i + \beta \bar{\mathrm{X}}_i + \bar{u}_i \Rightarrow$$

$$\Rightarrow \bar{Y}_i = \alpha_i + \beta \bar{\mathrm{X}}_i + \bar{u}_i \quad (2)$$

Panel data models: Fixed Effects

Within Estimator

- By taking the difference (1)-(2) in equations (1) and (2)

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it} \quad (1)$$

and

$$\bar{Y}_i = \alpha_i + \beta \bar{\mathrm{X}}_i + \bar{u}_i \quad (2)$$

we obtain:

$$\mathrm{Y}_{it} - \bar{Y}_i = \beta(\mathrm{X}_{it} - \bar{\mathrm{X}}_i) + (u_{it} - \bar{u}_i)$$

$$Y_{it}^* = \beta X_{it}^* + u_{it}^* \quad (3)$$

- Within Estimator steps:
  - Apply OLS in equation (3) and estimate β, i.e. obtain $\hat{\beta}$
  - Using equation (2), estimate α_i, i.e. $\hat{\alpha_i} = \bar{Y}_i - \hat{\beta}\bar{\mathrm{X}}_i$
  - Computationally easy
  - Can not conduct hypothesis testing

Panel data models: Fixed Effects

First-difference Estimator

- Another way of estimating panel data models is by first-differencing the data: lagging the model and subtracting, the time-invariant components are eliminated, and the model

$$\Delta \mathrm{Y}_{i,t} = \beta \Delta \mathrm{X}_{i,t} + \Delta u_{i,t}$$

can be consistently estimated by pooled OLS. This is called the first-difference estimator

- The differences are defined as follows $\Delta \mathrm{Y}_{i,t} = \mathrm{Y}_{i,t} - \mathrm{Y}_{i,t-1}$, $\Delta \mathrm{X}_{i,t} = \mathrm{X}_{i,t} - \mathrm{X}_{i,t-1}$, $\Delta u_{i,t} = u_{i,t} - u_{i,t-1}$, for $t = 2, \dots, T$

- Its relative efficiency, and so reasons for choosing it against other consistent alternatives, depends on the properties of the error term. The first-difference estimator is usually preferred if the errors u_{it} are strongly persistent in time, because then the $\Delta u_{i,t}$ will tend to be serially uncorrelated.

Panel data models: Random Effects

The Random effects model

- Consider the following panel data model:

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it} \quad (1),$$

$$u_{it} \sim iid(0, \sigma^2)$$

- Suppose that $a_i \sim D(a, \omega^2)$, that is: $E(a_i) = a$ and $V(a_i) = \omega^2$
- Then, that $a_i = a + \mu_i$ (2), $\mu_i \sim iid\ D(0, \omega^2)$, and $\mathrm{E}(\mu_i) = 0$, and $\mathrm{V}(\mu_i) = \omega^2$
- In this model, we have two parameters (a, ω^2) instead of N parameters ($a, \mathrm{N} - 1$ dummy variables) with respect to the intercept
- The model can be written:

$$\mathrm{Y}_{it} = \alpha_i + \beta \mathrm{X}_{it} + u_{it} \Rightarrow$$

$$\Rightarrow \mathrm{Y}_{it} = a + \mu_i + \beta \mathrm{X}_{it} + u_{it} \Rightarrow$$

$$\Rightarrow \mathrm{Y}_{it} = a + \beta \mathrm{X}_{it} + (\mu_i + u_{it}) \Rightarrow$$

$$\Rightarrow \mathrm{Y}_{it} = a + \beta \mathrm{X}_{it} + v_{it}, \qquad \text{where} \qquad v_{it} = \mu_i + u_{it}$$

Panel data models: Random Effects

The Random effects model

- For the process

$$v_{it} = \mu_i + u_{it}$$

we observe that: $v_{i1} = \mu_i + u_{i1}, v_{i2} = \mu_i + u_{i2}, \ \dots, \ v_{iT} = \mu_i + u_{iT}$. Therefore, v_{it} contains a common component, μ_i, across time, and thus v_{it} is auto-correlated.

- Its mean is: $E(v_{it}) = E(\mu_i + u_{it}) = E(\mu_i) + E(u_{it}) = 0$

- The variance is:

$$V(v_{it}) = V(\mu_i + u_{it}) = V(\mu_i) + V(u_{it}) = \omega^2 + \sigma^2$$

- The covariance of v_{it} with v_{is}, $t \neq s$, is:

$$Cov(v_{it}, v_{is}) = E(v_{it} v_{is}) = E[(\mu_i + u_{it})(\mu_i + u_{is})] =$$

$$= E[\mu_i^2 + \mu_i u_{is} + u_{it}\mu_i + u_{it} u_{is}] =$$

$$= E\left[\mu_i^2\right] = V(\mu_i) = \omega^2 \neq 0,$$ there is auto-correlation at v_{it}

Panel data models: Random Effects

The Random effects model

- Therefore, the covariance matrix of $\boldsymbol{v_i} = (v_{i1}, v_{i2}, \dots, v_{iT})'$ is

$$\boldsymbol{\Omega} = \begin{bmatrix} \omega^2+\sigma^2 & \omega^2 & \cdots & \omega^2 \\ \omega^2 & \omega^2+\sigma^2 & \cdots & \omega^2 \\ \vdots & \vdots & \ddots & \vdots \\ \omega^2 & \omega^2 & \cdots & \omega^2+\sigma^2 \end{bmatrix}$$

- However, there is not heteroskedasticity. The covariances between the elements of $\boldsymbol{v_i} = (v_{i1}, v_{i2}, \dots, v_{iT})'$ and $\boldsymbol{v_j} = \left(v_{j1}, v_{j2}, \dots, v_{jT}\right)'$ are given by:

$$Cov\left(v_{it}, v_{jt}\right) = E\left(v_{it}v_{jt}\right) = E\left[(\mu_i + u_{it})(\mu_j + u_{jt})\right] =$$

$$= E[\mu_i\mu_j + \mu_i u_{jt} + u_{it}\mu_j + u_{it}u_{jt}] = 0$$

- Thus,

$$\text{Cov}\begin{pmatrix} \boldsymbol{v_1} \\ \boldsymbol{v_2} \\ \vdots \\ \boldsymbol{v_N} \end{pmatrix} = \begin{bmatrix} \boldsymbol{\Omega} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Omega} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \boldsymbol{\Omega} \end{bmatrix}$$

Panel data models:

Fixed or Random Effects Model (Hausman test)

- **Decide between fixed or random effects model: we can run the Hausman test**
- Null hypothesis: the preferred model is random effects
  vs. the alternative the fixed effects (see Green, 2008, chapter 9).
- Steps:
  - Run a fixed effects model and save the estimates
  - Run a random model and save the estimates
  - Perform Hausman test. If the p-value is significant (for example a=0.05 > p-value) then use fixed effects, if not use random effects

- R command:
  - `fixed <- plm(y ~ sf1, data=data, index=c("country"), model="within")`
  - `random <- plm(y ~ sf1, data=data, index=c("country"), model="random")`
  - `phtest(fixed, random)`

Panel data models:

Tests - Diagnostics

- **Breusch-Pagan Lagrange Multiplier for random effects**
- The LM test helps you decide between a random effects regression and a simple OLS regression
- The null hypothesis in the LM test: no panel effect (i.e. OLS better). That is, no significant difference across units (i.e. no panel effect)

- R command:
  - pool <- plm(y ~ sf1, data = data, model="pooling")
  - plmtest(pool, type=c("bp"))

Panel data models:

Tests - Diagnostics

- **Breusch-Pagan Lagrange Multiplier test for cross-sectional dependence in panels**
- Cross-sectional dependence is a problem in panel data (especially with long time series)
- The null hypothesis in the Breusch-Pagan/LM Cross-sectional dependence tests is that residuals across units are not correlated
- Breusch-Pagan/LM (cross-sectional dependence) tests are used to test whether the residuals are correlated across units

- R commands:
  - Breusch-Pagan Lagrange Multiplier test for cross-sectional dependence in panels
  - `fixed <-plm(y ~ sf1, data=data, index=c("country"), model="within")`
  - `pcdtest(fixed, test = c("lm"))`

  - Pesaran test for cross-sectional dependence in panels
  - `pcdtest(fixed, test = c("cd"))`

Panel data models:

Testing for serial correlation

- **Breusch-Godfrey/Wooldridge test for serial correlation in panel models**
- Serial correlation tests apply to panel data. The null is that there is not serial correlation

- R commands: (required package: lmtest)
  - fixed <-plm(y ~ sf1, data=data, index=c("country"), model="within")
  - pbgtest(fixed)

Panel data models:

Testing for heteroskedasticity

- **Breusch-Pagan test for heteroskedasticity**
- The null hypothesis for the Breusch-Pagan test is homoskedasticity
- If hetersokedaticity is detected we can use robust covariance matrix to account for it, or model the conditional variances (using, for example, ARCH/GARCH type models)

- R commands: (required package: lmtest)
  - bptest(y ~ sf1 + factor(country), data = data, studentize=F)

Panel data models:

Controlling for heteroskedasticity

- Robust covariance matrix estimation (Sandwich estimator)
- The ‘vcovHC’ function estimates three heteroskedasticity-consistent covariance estimators:
  - "white1": for general heteroskedasticity but no serial correlation (recommended for random effects)
  - "white2“: is "white1" restricted to a common variance within groups (recommended for random effects)
  - "arellano“: both heteroskedasticity and serial correlation (recommended for fixed effects)
- The following options can be applied:
  - HC0 : heteroskedasticity consistent (default)
  - HC1,HC2, HC3 : Recommended for small samples. HC3 gives less weight to influential observations
  - HC4 : small samples with influential observations
  - HAC : heteroskedasticity and autocorrelation consistent (type ?vcovHAC for more details)
- R commands: (required package: lmtest)
  - fixed <-plm(y ~ sf1, data=data, index=c("country"), model="within")
  - coeftest(fixed) # Original coefficients
  - coeftest(fixed, vcovHC) # Heteroskedasticityconsistent coefficients
  - coeftest(fixed, vcovHC(fixed, method = "arellano")) # Heteroskedasticity consistent coefficients (Arellano)
  - random <-plm(y ~ sf1, data=data, index=c("country"), model="random")
  - coeftest(random) # Original coefficients
  - coeftest(random, vcovHC) # Heteroskedasticity consistent coefficients

Panel data models: Application to R

- Several panel data models will be implemented in R
- See corresponding R-file

Thank you