Gravity with Strategic Behavior

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Strategic Behavior in International Trade

- Gains from international trade depend on how other countries behave:
  - Politically, it may be infeasible to open the market to countries that are not themselves open
  - Faced with other countries subsidizing exports, may be optimal to subsidize own exports
- This is why we need organizations like the WTO, or free trade areas like the EU and NAFTA
- Estimation methods of the Gravity equation have ignored this
  - Making assumptions in line with competitive behavior
- This paper estimates a Gravity equation consistent with the idea of strategic behavior

Gravity and Competitive Behavior

Consider a standard version of the Gravity equation:

$$\log(x_{ijt}) = \gamma_t + \beta_r \log(GDP_{it}) + \beta_s \log(GDP_{jt}) + \eta Z_{ijt} + \alpha_{ri} + \alpha_{sj} + \epsilon_{ijt}$$

- Typically, we estimate this via OLS/ Panel Data
  - Fancier techniques include Santos Silva & Tenreyro (2006), or Andersen & Van Wincoop (2002)
- A common theme is the assumption of independent ϵ_{ijt} (usually $\sim \mathcal{N}(0, \sigma^2)$)
  - Country i cannot react to a change in country j's policy since $Cov(\epsilon_{ijt}, \epsilon_{jit}) = 0$
- Strategic behavior implies that these errors are not independent
  - Correlation makes OLS or Panel data estimates unreliable

What we Propose

- A network estimation as in Hoff (2003) can more accurately capture strategic behavior
  - Proposes the use of random effects rather than fixed effects
  - Random effects produce precise estimates when the errors are correlated (Laird and Ware, 1982)
- Random effects can also capture other effects that are prevalent in international trade:
  - When two countries increase bilateral trade, trade increases in a third country (transitivity)
  - When two countries increase bilateral trade, trade decreases in a third country (balance)
- In addition, we drop the assumption of independence in the error term
  - Instead, we model a covariance structure and estimate it

Modeling Exporter and Importer Effects

- Different levels of openness imply that countries have different intercepts
  - Typically modeled via fixed exporter and importer effects
- We model the different intercepts via random effects
  - Country effects are realizations of a Normal distribution, with zero mean and a variance to be estimated
  - This incorporates explicit correlations across country effects
- We model a correlation between exporter and importer effects within countries
  - Countries that are more open to export tend to be more open to import as well
- Random effects are more efficient than fixed effects
  - They reduce the number of parameters: estimate a variance rather than $2 \times N$ fixed effects
  - They deliver precise estimates when the error terms are correlated (Laird and Ware, 1982)

Capturing Transitivity and Balance

- Hoff (2003) shows that multiplicative random effects can capture this behavior
- These enter the Gravity equation as the inner product of an exporter vector and an importer one:

$$\log(x_{ijt}) = \gamma_t + \beta_r \log(GDP_{it}) + \beta_s \log(GDP_{jt}) + \eta Z_{ijt} + \alpha_{ri} + \alpha_{sj} + \mathbf{u_i^T v_j} + \epsilon_{ijt}$$

- Multiplicative random effects can also correct for missing variables (Hoff, 2021)
- We argue that they proxy for bilateral trade barriers

What we do

- We estimate a Gravity equation within Networks as in Hoff (2021)
- We compare our estimates with Panel Data estimates
- We produce a new openness index based on a mean-reversion of each country's trade barriers
- We use this index to explore the relationship between openness and other macro variables

What we find

- We find big differences with Panel data
  - Our estimated exporter GDP effect is one third of that in Panel Data
- We find strong evidence of openness associated to
  - Convergence - open countries converge faster
  - Wealth - open countries are richer
  - Inequality - open countries are more equal

Related Literature

- Gravity estimation in Networks
  - Hoff (2021)
- Theoretical models of strategic behavior
  - Beshkar and Lashkaripour (2020a, 202b), Beshkar, Chang and Song (2024), Brander and Spencer (2016), Leahy and Neary (2009), Bagwell and Staiger (1994).
- Effects of the U.S.-China trade war on third countries
  - Nicita (2019), Fajgelbaum et al. (2023), Nantembele (2023), Mayr-Dorn (2023), Choi and Nguyen (2023), Alfaro and Choi (2023)
- Evidence of correlated reciprocal trade barriers (retaliation)
  - Fajgelbaum et al. (2020)

The Model

We estimate the following version of the Gravity equation:

$$\log(x_{ijt}) = \alpha_t + \beta_r \log y_{it} + \beta_s \log y_{jt} + \beta_d \log d_{ij} + \beta_l a_{lij} + \beta_c a_{cij} + \beta_{tij} a_{tij} + u_i^T v_j + r_i + s_j + \varepsilon_{ijt}$$

- x_{ijt} is imports in country i from j at time t
- y is GDP
- a's are common language, colonial ties and border
- d is distance

Our Assumptions vs. Panel Data's

Split the Gravity equation into two components:

- Fixed effects:
$$\alpha_t + \beta_s \log y_{it} + \beta_r \log y_{jt} + \beta_d \log d_{ij} + \beta_l a_{lij} + \beta_c a_{cij} + \beta_t a_{tij}$$
- Random effects:
$$u_i^T v_j + r_i + s_j + \varepsilon_{ijt}$$
- The fixed effects part is close to standard analysis
- We detail the assumptions on random effects next

Additive Random Effects

- Country random effects follow

$$\begin{pmatrix} r_i \\ s_i \end{pmatrix} \sim \mathcal{N}_2 \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_r^2 & \sigma_{rs} \\ \sigma_{rs} & \sigma_s^2 \end{pmatrix} \right]$$

- The error term ε_{ijt} follows

$$\begin{pmatrix} \varepsilon_{ijt} \\ \varepsilon_{jit} \end{pmatrix} \sim \mathcal{N}_2 \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\varepsilon^2 & \rho\sigma_\varepsilon \\ \rho\sigma_\varepsilon & \sigma_\varepsilon^2 \end{pmatrix} \right]$$

Multiplicative Random Effects

- Intuitively, one can think of multiplicative random effects as country-pair dummies
- Dummies require too many degrees of freedom, producing unreliable estimates
  - With N countries, need $N \times (N-1)$ point estimates (over 34,000 presently)
- Multiplicative random effects propose that bilateral trade barriers between countries i and j are

$$u_i^T v_j$$

  where $u_i, v_j \sim N_{2k}(\mathbf{0}, \Sigma)$ and k is the dimensionality of the vectors ▸ Time-Changing Barriers
- Thus, rather than $N \times (N-1)$ parameters we estimate the $(2k)^2$ elements in Σ
  - We set $k = 4$, so we estimate 64 parameters

Transitivity and Balance

- For two countries A and B assume

$$u_A = \begin{pmatrix} + \\ + \end{pmatrix} \quad v_A = \begin{pmatrix} + \\ + \end{pmatrix} \quad u_B = \begin{pmatrix} + \\ + \end{pmatrix} \quad v_B = \begin{pmatrix} + \\ + \end{pmatrix}$$

  These countries trade more than accounted for by observables since $u_A^T v_B > 0$ and $u_B^T v_A > 0$

- Transitivity: more trade between A and B imply more trade between A and C and between B and C

$$u_C = \begin{pmatrix} + \\ + \end{pmatrix} \quad v_C = \begin{pmatrix} + \\ + \end{pmatrix} \Rightarrow u_i^T v_C > 0 \;\; \& \;\; u_C^T v_i > 0, \quad i = A, B$$

- Balance: more trade between A and B imply less trade between A and C and between B and C

$$u_C = \begin{pmatrix} - \\ - \end{pmatrix} \quad v_C = \begin{pmatrix} - \\ - \end{pmatrix} \Rightarrow u_i^T v_C < 0 \;\; \& \;\; u_C^T v_i < 0, \quad i = A, B$$

Relations Captured by Our Framework (Hoff, 2021)

Covariance	Co-Movement Between	Value
$Cov(x_{ijt}, x_{ikt})$	Exports from country i to all partners	σ_r^2
$Cov(x_{ijt}, x_{kjt})$	Imports into country j from all partners	σ_s^2
$Cov(x_{ijt}, x_{jkt})$	Imports and exports in country j	σ_{rs}
$Cov(x_{ijt}, x_{jit})$	Exports and imports between countries i and j	$2\sigma_{rs} + \rho\sigma_\varepsilon$

Data

- Trade data from COMTRADE
- GDP data from WDI
- Distance from Centre for Prospective Studies and International Information
- Language, borders, colonial ties from Fouquin and Hugot (2016)
- Time period: 2000 through 2019
  - End in 2019 to avoid COVID
  - Don't start too far back to capture current trade practices

Results

- We estimate the model using the *AMEN* package in *R*
  - Additive and Multiplicative Random Effects in Networks
- Our baseline sets $k = 4$
  - We also compute results for $k = 2$ and $k = 0$

Estimation Results

Parameter	$k = 4$	$k = 2$	$k = 0$
log Importer GDP	0.716	0.695	0.710
	(0.017)	(0.017)	(0.014)
log Exporter GDP	0.315	0.290	0.312
	(0.017)	(0.017)	(0.015)
log Distance	-0.650	-0.776	-1.311
	(0.008)	(0.007)	(0.007)
Common Colonial Ties	0.811	1.027	0.933
	(0.054)	(0.056)	(0.059)
Common Language	1.006	1.113	1.680
	(0.020)	(0.021)	(0.019)
Common Border	2.445	2.222	2.253
	(0.041)	(0.044)	(0.045)
σ_s^2	14.268	11.891	6.745
	(2.111)	(1.632)	(0.823)
σ_{rs}	26.383	20.234	11.060
	(3.751)	(2.883)	(1.400)
σ_r^2	51.259	37.031	20.762
	(7.172)	(5.362)	(2.574)
ρ	0.2674	0.312	0.359
	(0.002)	(0.002)	(0.001)
σ_ε^2	12.168	13.507	15.371
	(0.022)	(0.025)	(0.026)

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- Estimates consistent with the literature
  - Larger GDP, larger trade
  - Larger distance, lower trade
- Changing k affects mostly the bilateral effects
  - MRE are about country-pair interactions
- Results support retaliation in trade barriers
  - $Cov(\varepsilon_{ijt}, \varepsilon_{jit}) = \rho\sigma_\epsilon > 0$
- More open to imports $\leftrightarrow$ more open to exports
  - $Cov(r, s) = \sigma_{rs} > 0$

Comparison to Panel Data

Parameter	Networks, $k = 0$	Panel Data
log Importer GDP	0.710	0.622
	(0.014)	(0.038)
log Exporter GDP	0.312	1.074
	(0.015)	(0.018)
log Distance	-1.311	-1.300
	(0.007)	(0.006)
Common Colonial Ties	0.933	0.925
	(0.059)	(0.052)
Common Language	1.680	1.684
	(0.019)	(0.017)
Common Border	2.253	2.274
	(0.045)	(0.041)

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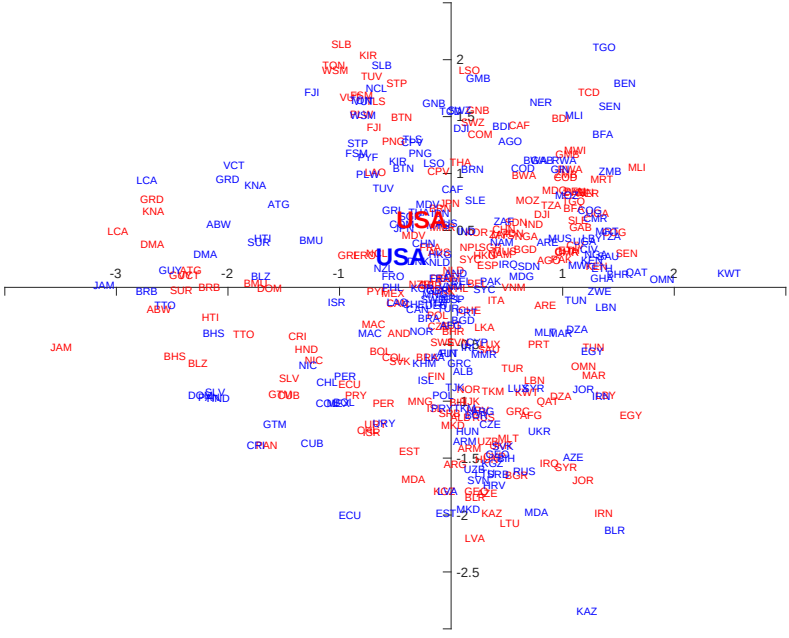
log Exporter GDP	**0.312**	**1.074**
	(0.015)	(0.018)
log Distance	-1.311	-1.300
	(0.007)	(0.006)
Common Colonial Ties	0.933	0.925
	(0.059)	(0.052)
Common Language	1.680	1.684
	(0.019)	(0.017)
Common Border	2.253	2.274
	(0.045)	(0.041)

- Panel Data exaggerates role of exporter GDP
  - By a factor of 3!
- It underestimates role of importer GDP
  - Estimates closer than with exporter GDP
- Other estimates are close
  - Within 2 standard deviations

Illustrating the Multiplicative Random Effects with $k = 2$



Constructing an Openness Index

- Recall that additive and multiplicative random effects can be thought of as trade barriers
  - If these terms are positive, they increase trade
  - If these terms are negative, they reduce trade
  - Their magnitude determines the relevance

- Hoff (2003): these effects are causal since random effects account for the dependence structure
  - The observations are independent (random effects account for the dependence structure, Hoff, 2003)
  - The expected value of the error term is zero when conditioning by independent variables ($E(\epsilon|X) = 0$)

- We rely on a counterfactual that restores the effects to the mean to measure openness
  - This counterfactual sets $r_i, s_i, u_i, v_i = 0$ and measures the change in trade
  - We do this to construct three indexes: export, import, and export + import

The Top 5

Overall	Δ_T	Exporter	Δ_x	Importer	Δ_m
THA	0.4231	CHN	-0.3797	THA	-0.0089
CHN	0.6156	JPN	0.0273	GUY	0.0294
USA	0.6519	USA	0.2173	USA	0.4346
JPN	0.6569	KOR	0.4247	NLD	0.4516
KOR	1.1290	THA	0.4320	BLR	0.4701

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KOR	1.1290	THA	0.4320	BLR	0.4701

Interpretation:

- Thailand would increase the sum of imports and exports by 42%
- China would reduce its exports by 38%
- Thailand would reduce its imports by 0.9%

Bottom 5

Openness and Macroeconomic Outcomes

- An old question is whether there is a relationship between openness and other macro variables
- The main problem lies in how to measure openness
- We focus on convergence, GDP per capita, and inequality

Openness and Convergence

- Sachs and Warner (1995) finds a correlation between openness and convergence
  - Also Wacziarg and Welch (2008), Ben David (1993), Dollar (1992)
- The problem is that Sachs and Warner define openness not only in terms of trade
  1. Average tariffs
  2. Non-tariff barriers
  3. Socialist vs. capitalist system
  4. State monopoly of exports
  5. Black market premium
- Rodriguez and Rodrik (2000) show that, when only focusing on (1) and (2), there is no correlation
  - They also poke holes in the other findings
- We look for a correlation between openness and convergence using our index

Two Exercises to Study Openness and Convergence

- Test for convergence separately for open and closed countries
  - Consider the standard convergence regression

$$g_{i,2000-2019} = \alpha + \gamma_1 \log(GDPpc_{i,2000})$$

  - $\gamma_1 < 0$ under convergence
  - The smaller the γ_1, the stronger the convergence
  - We estimate this for two samples: more open than the median, and the rest

- Add an interaction term and pool all countries together

$$g_{i,2000-2019} = \alpha + \gamma_1 \log(GDPpc_{i,2000}) + \gamma_2 Index_i + \gamma_3 \log(GDPpc_{i,2000}) Index_i$$

  - $\gamma_3 < 0$ would suggest that more open countries converge faster

Open Countries Converge Faster

Coefficient	No Controls	Open countries	Closed countries	Interaction Term
Overall Openness				
γ_1	-0.0041	-0.0056	-0.0044	-0.0084
	(0.0012)	(0.0014)	(0.0014)	(0.0020)
γ_2	-	-	-	0.0048
				(0.0020)
γ_3	-	-	-	-0.0004
				(0.0002)
N	181	90	91	181
Openness to Export				
γ_1	-	-0.0059	-0.0044	-0.0095
		(0.0012)	(0.0014)	(0.0019)
γ_2	-	-	-	0.0086
				(0.0027)
γ_3	-	-	-	-0.0008
				(0.0003)
N	-	90	91	181
Openness to Import				
γ_1	-	-0.0059	-0.0038	-0.0050
		(0.0012)	(0.0013)	(0.0019)
γ_2	-	-	-	0.0040
				(0.0060)
γ_3	-	-	-	-0.0002
				(0.0007)
N	-	90	91	181

Openness and Wealth

- Romer and Frankel (1999) find empirically a link between trade and GDP per capita
- Rodriguez and Rodrik (2000) claim this is about trade volumes, not openness
- We explore this by correlating our indexes with GDP per capita
  - We consider every year from 2000 to 2019 for GDP per capita

Open Countries are Wealthier

Correlations between each Index and $GDPpc_t$, $t = 2000, \ldots, 2019$

	Overall Openness	$p-value$	*Openness to Export*	$p-value$	*Openness to Import*	$p-value$
Mean	0.3427	2×10^{-6}	0.3790	1.9×10^{-7}	0.2180	0.0032
Std dev.	0.0101	1.8×10^{-6}	0.0120	2.018×10^{-7}	0.0087	0.0012

Openness and Inequality

- Heckscher-Ohlin
  - Openness reduces inequality for poor countries
  - Openness increases inequality for rich countries
- Dorn et al. (2022) find evidence supporting these effects
  - Although some results are driven by outliers
- We correlate our indexes with the Gini coefficient
  - Recall Gini = 0 implies total equality, and Gini = 1 implies extreme inequality
  - We use the average of the Gini coefficient between 2000 and 2019 (WDI)

Open Countries Experience Less Inequality

	Overall Openness	*Openness to Export*	*Openness to Import*
Correlation	-0.1855	-0.1776	-0.1723
$p-value$	(0.0217)	(0.0281)	(0.0332)

Open Countries Experience Less Inequality

	Overall Openness	*Openness to Export*	*Openness to Import*
All countries			
Correlation	-0.1855	-0.1776	-0.1723
$p-value$	(0.0217)	(0.0281)	(0.0332)
Countries richer than the median			
Correlation	-0.1192	-0.1057	-0.1279
$p-value$	(0.3017)	(0.3602)	(0.2675)
Countries at least as poor as the median			
Correlation	-0.1922	-0.1883	-0.1691
$p-value$	(0.0963)	(0.1033)	(0.1442)

- The correlations are stronger for poor countries, in line with Heckscher-Ohlin

Correlations with Existing Openness Indexes

Openness Indicator	Overall	Export	Import
$\frac{\text{Imp.+Exp.}}{\text{GDP}}$	0.0626	0.0480	0.0850
	(0.4161)	(0.5329)	(0.2693)
Tariffs (simple avg.)	-0.3829	-0.4108	-0.2446
	(0.0000)	(0.0000)	(0.0014)
Tariffs (weighted avg.)	-0.4942	-0.5229	-0.3325
	(0.0000)	(0.0000)	(0.0000)
Jaumotte et al. (2013)	0.1853	0.1744	0.1760
	(0.0334)	(0.0455)	(0.00436)
Duernecker et al. (2022)	0.8273	0.8568	0.6095
	(0.0000)	(0.0000)	(0.0000)
Heritage Foundation	0.4067	0.4358	0.2658
	(0.0000)	(0.0000)	(0.0005)
Freedom Fraser	0.4977	0.5085	0.3745
	(0.0000)	(0.0000)	(0.0000)

Conclusion

- The empirical trade literature often ignores strategic behavior when estimating Gravity equations
- This paper proposes a way to deal with it
- The temptation of using “off-the-shelf” models typically drives the economists’ actions
- Hopefully, Hoff’s *AMEN* package will become “off-the-shelf”

Time-Varying Bilateral Trade Barriers

- Note that our assumptions do not imply that trade barriers are constant
- They can change in time as long as all barriers change in the same way
- They can change in time differently, as temporary changes centered around a mean

$$\tau_{ijt} = u_i^T v_j + a_t + \nu_{ijt}$$

a_t is absorbed by time fixed effects and ν_{ijt} is absorbed by the error term

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The Bottom 5

Overall	Δ_T	Exporter	Δ_x	Importer	Δ_m
STP	16.3063	TLS	11.0130	LSO	5.5085
TLS	17.6761	GNB	11.1028	TLS	6.6632
BTN	17.9086	BTN	11.2317	BTN	6.6769
FSM	20.1333	FSM	12.9384	PLW	6.9852
PLW	20.2666	PLW	13.2814	FSM	7.1948

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FSM	20.1333	FSM	12.9384	PLW	6.9852
PLW	20.2666	PLW	13.2814	FSM	7.1948

Interpretation:

- Palau would increase the sum of imports and exports by 2,027%
- Palau would increase its exports by 1,328%
- Micronesia would increase its imports by 719%

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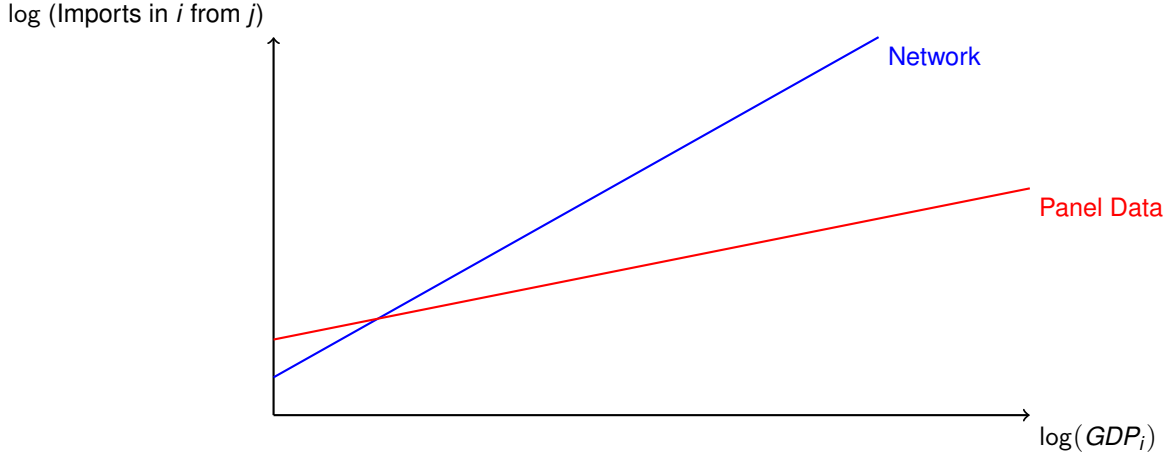
The Expectation of the Error Term Given Observables



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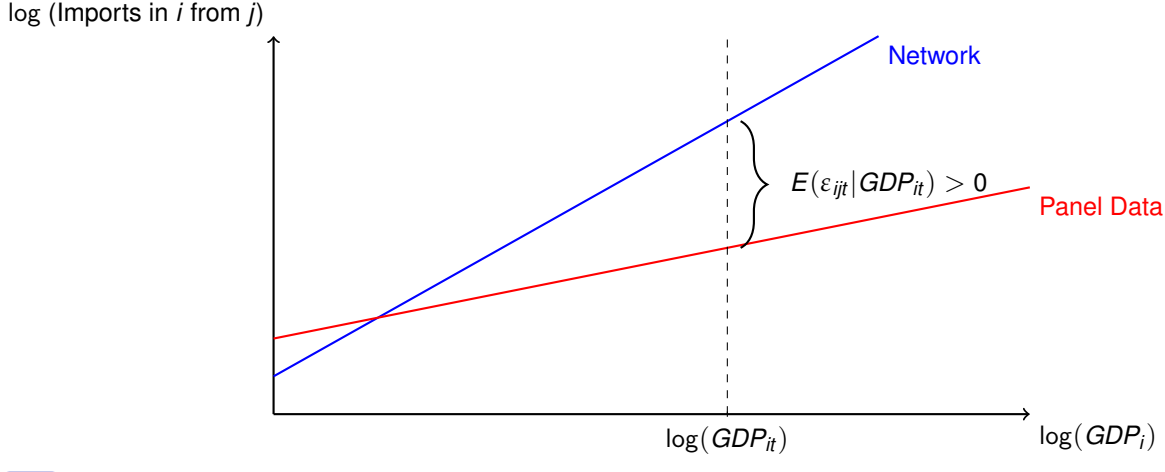

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