An Overview of Gravity Estimation

International Trade (PhD), Fall 2024

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Background

- Quantitative trade models are used to examine the counterfactual impacts of shocks (*e.g.*, conflict, trade war, improvements in transport infrastructure).
- To conduct counterfactual welfare analysis we must know
  - (a) how the shock we intend to study modifies trade costs: $\widehat{\tau}_{in}^{-\epsilon}$
  - (b) the trade elasticity, ϵ
- With information on (a) and (b), we can compute the change welfare as

$$\widehat{W}_i = \frac{\widehat{Y}_i}{\widehat{P}_i}, \qquad \widehat{P}_i = \left[\sum_n \lambda_{ni} \, \hat{\tau}_{ni}^{-\epsilon} \, \widehat{Y}_n^{-\epsilon} \right]^{-\frac{1}{\epsilon}}$$

where $\widehat{Y}_i$ can be calculated using baseline trade shares, $\{\lambda_{in}\}_{i,n}$, and GDP data, $\{Y_i\}_i$:

$$\widehat{Y}_i Y_i = \sum_{n=1}^{N} \left[\frac{\lambda_{in} \, \hat{\tau}_{in}^{-\epsilon} \, \widehat{Y}_i^{-\epsilon}}{\sum_{j=1}^{N} \lambda_{jn} \, \hat{\tau}_{jn}^{-\epsilon} \, \widehat{Y}_j^{-\epsilon}} \widehat{Y}_n Y_n \right]$$

Overview of Commonly-Used Estimation Approaches

- Approaches for estimating trade frictions and $\hat{\tau}_{in}^{-\epsilon}$

  1. **gravity estimation:** estimates how factors like geo-distance, trade agreements, or conflict influence trade costs $\longrightarrow$ identifies $\hat{\tau}_{in}^{-\epsilon}$ if these factor counterfactually change

  2. **residual approach:** recovers $\tau_{in}^{-\epsilon}$ from observed trade flows $\longrightarrow$ identifies $\hat{\tau}_{in}^{-\epsilon}$ over time

  3. **natural experiment:** estimate the causal effect of an local shock on observed trade costs (*e.g.*, the impact of railroad development in Raj – Donaldson, 2018)

- Approaches for estimating the trade elasticity

  1. use tariff data (Caliendo-Parro, 2014)

  2. use inter-national prices gaps (Eaton-Kortum (2002); Simonovska-Waugh (2013))

  3. use freight data (Shapiro, 2015)

Gravity Estimation

Gravity Estimation: Theoretical Foundation

Gravity Equation: quantitative trade models predict that trade flows are given by

$$X_{in} = \frac{\tilde{\chi}_i \left(\tau_{in} Y_i\right)^{-\epsilon}}{\sum_{j=1}^{N} \tilde{\chi}_j \left(\tau_{jn} Y_j\right)^{-\epsilon}} E_n$$

Gravity Estimation: Theoretical Foundation

Gravity Equation: quantitative trade models predict that trade flows are given by

$$X_{in} = \tau_{in}^{-\epsilon} \times \underbrace{\tilde{\chi}_i \left(Y_i\right)^{-\epsilon}}_{\Phi_i \sim \text{export FE}} \times \underbrace{\frac{E_n}{\sum_{j=1}^{N} \tilde{\chi}_j \left(\tau_{jn} Y_j\right)^{-\epsilon}}}_{\Omega_n \sim \text{importer FE}}$$

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Gravity Estimation: Theoretical Foundation

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Parametrizing τ_{in} in terms of observables: iceberg trade costs represent impediments such as policy barriers, transport costs, and contractual frictions, which depend on geo-distance, FTAs, common language, common border, conflict, etc.

$$\tau_{in}^{-\epsilon} = \exp\left(\beta_d \ln \text{Dist}_{in} + \beta_f \text{FTA}_{in} + \beta_l \text{Lang}_{in} + \beta_b \text{Border}_{in} + \beta_c \text{Conflict}_{in} + \varepsilon_{in}\right)$$

The Relationship between Trade and Distance

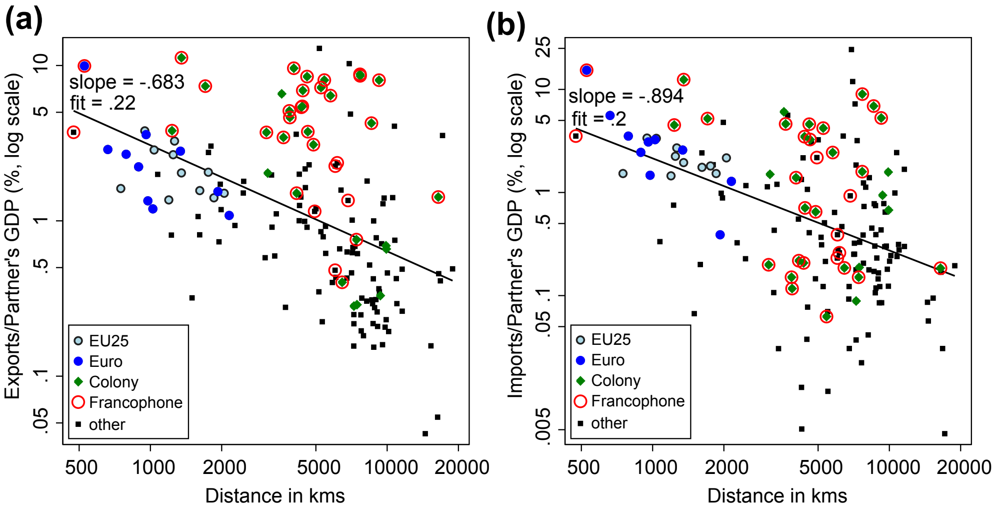
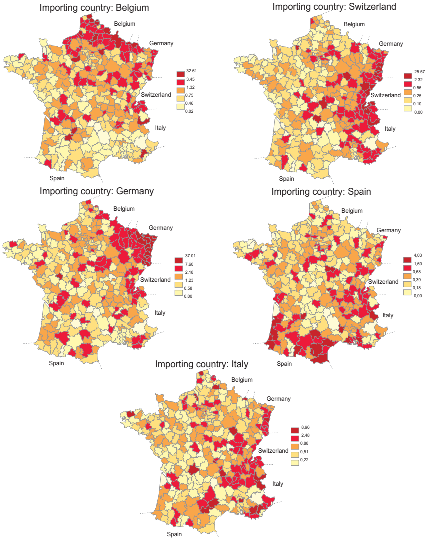


Figure 3.2 Trade is Inversely Proportional to Distance; (a) France's Exports (2006); (b) France's Imports (2006)

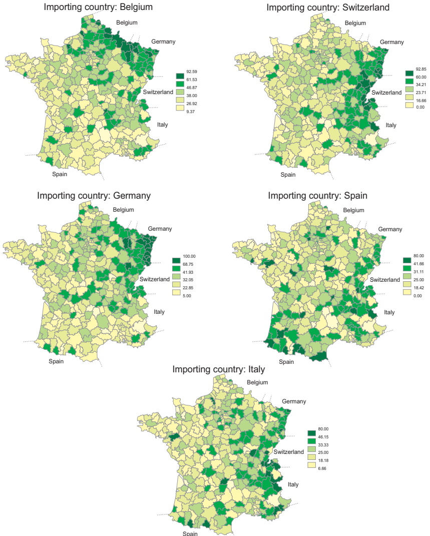
The Relationship between Trade and Distance: *Intensive Margin*

Figure 1: Mean value of individual-firm exports (single-region firms, 1992)



The Relationship between Trade and Distance: *Extensive Margin*

Figure 2: Percentage of firms which export (single-region firms, 1992)



Gravity Estimation: The Estimating Equation

Combining the gravity equation with our parameterization for τ_{in} yields the following estimating equation

$$\ln X_{in} = \underbrace{\beta_d \ln \text{Dist}_{in} + \text{Controls}_{in}}_{-\epsilon \ln \tau_{in}} + \widetilde{\Phi}_i + \widetilde{\Omega}_n + \varepsilon_{in}$$

- Controls_{in} represents non-distance variables such as border, FTA, conflict, etc.
- $\widetilde{\Phi}_i \equiv \ln \Phi_i \sim$ exporter fixed effect; $\widetilde{\Omega}_n \equiv \ln \Omega_n \sim$ importer fixed effect
- Φ_i and Ω_n are theory-consistent *iff* they satisfy

$$\Phi_i = \frac{Y_i}{\sum_{n'} \Omega_{n'} \tau_{in'}^{-\epsilon}}; \qquad \Omega_n = \frac{E_n}{\sum_{i'} \Phi_{i'} \tau_{i'n}^{-\epsilon}}$$

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Note: the naïve gravity estimation uses importer/export GDPs (Y_i and Y_n) as proxies for importer/exporter fixed effects (Φ_i and Ω_n) $\longrightarrow$ suffers from *omitted variable bias*

Two General Approaches to Gravity Estimation

1. **Structural gravity estimation:** estimate the gravity equation *s.t.* Φ_i and Ω_n satisfying equilibrium constraints:

$$\Phi_i = \frac{Y_i}{\sum_{n'} \Omega_{n'} \tau_{in'}^{-\epsilon}}; \qquad \Omega_n = \frac{E_n}{\sum_{i'} \Phi_{i'} \tau_{i'n}^{-\epsilon}}$$

2. **Reduced-form gravity estimation:** estimate the log-linear gravity equation with canned estimators (e.g., OLS, PPML) *without* explicitly accounting for the above equilibrium constraints.

Structural Gravity Estimation (Anderson & van Wincoop, 2003)

- Begin with an an initial guess for exporter/importer fixed effects, $\left\{\Phi_i^0, \Omega_n^0\right\}$, and perform the following iterative process:

  1. estimate the gravity equation using OLS to obtain an estimate for $\mathcal{T}_{in}$ in iteration (t):

$$\ln X_{in} = \underbrace{\beta_d^{(t)} \ln \text{Dist}_{in} + \text{Controls}_{in}}_{\log \mathcal{T}_{in}^{(t)}} + \widetilde{\Phi}_i^{(t-1)} + \widetilde{\Omega}_n^{(t-1)} + \varepsilon_{in}$$

  2. update fixed effects using the following system of equations and data on Y_i and E_n:

$$\Phi_i^{(t)} = \frac{Y_i}{\sum_{n'} \Omega_{n'}^{(t)} \mathcal{T}_{in'}^{(t)}}; \qquad \Omega_n^{(t)} = \frac{E_n}{\sum_{i'} \Phi_{i'}^{(t)} \mathcal{T}_{i'n}^{(t)}}$$

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- Repeat this process until convergence is achieved:
$$\mid \Phi_i^{(t)} - \Phi_i^{(t-1)} \mid \rightarrow 0; \qquad \mid \Omega_i^{(t)} - \Omega_i^{(t-1)} \mid \rightarrow 0 \qquad (\forall i)$$

Reduced-Form Gravity Estimation

OLS Estimation

- Estimating equation: $$\ln X_{in} = \underbrace{\beta_d \ln \text{Dist}_{in} + \text{Controls}_{in} + \widetilde{\Phi}_i + \widetilde{\Omega}_n}_{\boldsymbol{\beta}\cdot\mathbf{Z}_{in}} + \varepsilon_{in}$$
- Moment condition: $$\sum_{i,n} \mathbf{Z}_{in} \cdot \left(\ln X_{in} - \ln \hat{X}_{in}\right) = 0$$

PPML Estimation:

- Estimating equation: $$X_{in} = \exp\left(\underbrace{\beta_d \ln \text{Dist}_{in} + \text{Controls}_{in} + \widetilde{\Phi}_i + \widetilde{\Omega}_n}_{\boldsymbol{\beta}\cdot\mathbf{Z}_{in}}\right) + \varepsilon_{in}$$
- Moment condition: $$\sum_{i,n} \mathbf{Z}_{in} \cdot \left(X_{in} - \hat{X}_{in}\right) = 0$$

Which Reduced-Form Estimator: PPML or OLS?

- Advantages of the PPML estimator:
  1. it can naturally account for zeros
  2. the estimated fixed effects, $\hat{\Phi}_i$ and $\hat{\Omega}_i$, automatically satisfy the adding up equilibrium constraints (Fally, 2015)
  3. provides consistent estimates in the presence of heteroskedasticity.

- Disadvantage of the PPML estimator: it is prone to *small sample bias*.

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- User-written STATA routines for reduced-form gravity estimation
  - OLS: `reghdfe`
  - PPML: `ppmlhdfe`

A Meta-Analysis of Gravity Estimation Results

Table 3.4 Estimates of Typical Gravity Variables

	All Gravity				Structural Gravity			
Estimates:	**Median**	**Mean**	**s.d.**	**#**	**Median**	**Mean**	**s.d.**	**#**
Origin GDP	.97	.98	.42	700	.86	.74	.45	31
Destination GDP	.85	.84	.28	671	.67	.58	.41	29
Distance	−.89	−.93	.4	1835	−1.14	−1.1	.41	328
Contiguity	.49	.53	.57	1066	.52	.66	.65	266
Common language	.49	.54	.44	680	.33	.39	.29	205
Colonial link	.91	.92	.61	147	.84	.75	.49	60
RTA/FTA	.47	.59	.5	257	.28	.36	.42	108
EU	.23	.14	.56	329	.19	.16	.5	26
NAFTA	.39	.43	.67	94	.53	.76	.64	17
Common currency	.87	.79	.48	104	.98	.86	.39	37
Home	1.93	1.96	1.28	279	1.55	1.9	1.68	71

Notes: The number of estimates is 2508, obtained from 159 papers. Structural gravity refers here to some use of country fixed effects or ratio-type method.

Source: Head and Mayer (2014, Handbook Chapter)

Using Gravity Estimation to Guide Counterfactual Analyses

- The gravity estimation coefficients reveal how trade frictions change in response to external shocks, such as abolishing FTAs or regional conflicts.
- More specifically, the gravity estimation specifies trade frictions as a function of observed geopolitical factors:

$$\tau_{in}^{-\epsilon} = \exp\left(\beta_d \ln \text{Dist}_{in} + \beta_f \text{FTA}_{in} + \beta_l \text{Lang}_{in} + \beta_b \text{Border}_{in} + \beta_c \text{Conflict}_{in} + \varepsilon_{in}\right)$$

- Suppose we want to determine in the impacts of abolishing FTAs: $\text{FTA}_{in} \to \text{FTA}'_{in} = 0$
- The resulting change in the trade frictions can be calculated using the coefficient of FTAs (β_f) from the gravity estimation:

$$\hat{\tau}_{ni}^{-\epsilon} = \left(\frac{\tau'_{ni}}{\tau_{ni}}\right)^{-\epsilon} = \frac{e^{\beta_f \text{FTA}'_{in}}}{e^{\beta_f \text{FTA}_{in}}} = e^{-\beta_f \text{FTA}_{in}}$$

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$$\hat{\tau}_{ni}^{-\epsilon} = \begin{cases} e^{-\beta_f} & \text{if } \text{FTA}_{in} = 1 \\ 1 & \text{if } \text{FTA}_{in} = 0 \end{cases}$$

Using Gravity Estimation to Guide Counterfactual Analyses

- Following Head and Mayer's meta-analysis, $\beta_f \approx 0.3$, across structural gravity estimations, thus:

$$\text{aboloshing FTAs} \qquad \sim \qquad \hat{\tau}_{in}^{-\epsilon} = e^{-0.3\text{FTA}_{in}}$$

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The Residual Approach to Estimating Trade Costs

- If we are only interested in determining the magnitude of τ_{in}^{ϵ}, we can use the residual approach developed by Head and Ries (2001).

- This approach infer $\tau_{in}^{-\epsilon}$ from trade flows using the theoretical gravity equation

$$X_{in} = \frac{\tilde{\chi}_i \left(\tau_{in} Y_i\right)^{-\epsilon}}{\sum_{j=1}^{N} \tilde{\chi}_j \left(\tau_{jn} Y_j\right)^{-\epsilon}} E_n,$$

- Note: the above equation is consistent with the *Armington*, *EK*, *Krugman*, or *Melitz-Pareto* models $\longrightarrow$ the implied Head-Ries index is model-blind.

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The Residual Approach to Estimating Trade Costs

- Assume that $\tau_{ii} = 1$, then the gravity equation implies

$$\frac{X_{ni}}{X_{ii}} = \frac{\tilde{\chi}_n}{\tilde{\chi}_i} \left(\frac{Y_n}{Y_i}\right)^{-\epsilon} \tau_{ni}^{-\epsilon}; \qquad \frac{X_{in}}{X_{nn}} = \frac{\tilde{\chi}_i}{\tilde{\chi}_n} \left(\frac{Y_i}{Y_n}\right)^{-\epsilon} \tau_{in}^{-\epsilon}$$

- Assume that $\tau_{ni} = \tau_{in}$, then we can calculate Head-Ries index for trade costs as follows:

$$\tau_{ni}^{-\epsilon} = \tau_{in}^{-\epsilon} = \sqrt{\frac{X_{ni} X_{in}}{X_{ii} X_{nn}}}$$

- **Note:** symmetric trade costs are inconsistent with evidence that poor countries face systematically higher export costs than rich countries (Waugh, 2011 AER).

Trade Cost Estimates Based on the Residual Approach

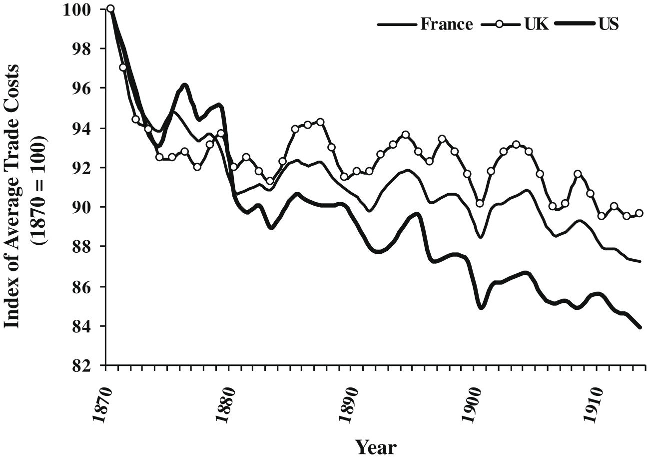

Fig. 2. Index of average trade costs for France, the UK, and the US, 1870–1913.

Source: Jacks, Meissner, and Novy (2010)

Interpreting the Decline in Trade Costs Indexes

Two ways to interpret the decline (over time) in the Head-Ries index

1. Trade costs, τ_{ni}'s, are falling due to trade liberalization, containerization, etc.
2. The trade elasticity, ϵ, is declining because of the changing composition of traded goods or changes to international technology dispersion.

How Large are the Trade Costs Implied by Gravity Estimation?

TABLE 7
Tariff Equivalent of Trade Costs

	method	data	reported by authors	$\sigma=5$	$\sigma=8$	$\sigma=10$
all trade barriers						
Head and Ries (2001) U.S.-Canada, 1990-1995	new	disaggr.	48 ($\sigma=7.9$)	97	47	35
Anderson and van Wincoop (2003) U.S.-Canada, 1993	new	aggr		91	46	35
Eaton and Kortum (2002) 19 OECD countries, 1990 750-1500 miles apart	new	aggr.	48–63 ($\sigma=9.28$)	123–174	58–78	43–57
national border barriers						
Wei (1996) 19 OECD countries, 1982-1994	trad.	aggr.	5 ($\sigma=20$)	26–76	14–38	11–29
Evans (2003a) 8 OECD countries, 1990	trad.	disaggr.	45 ($\sigma=5$)	45	30	23
Anderson and van Wincoop (2003) U.S.-Canada, 1993	new	aggr.	48 ($\sigma=5$)	48	26	19
Eaton and Kortum (2002) 19 OECD countries, 1990	new	aggr.	32–45 ($\sigma=9.28$)	77–116	39–55	29–41
language barrier						
Eaton and Kortum (2002) 19 OECD countries, 1990	new	aggr.	6 ($\sigma=9.28$)	12	7	5
Hummels (1999) 160 countries, 1994	new	disaggr.	11 ($\sigma=6.3$)	12	8	6
currency barrier						
Rose and van Wincoop (2001) 143 countries, 1980 and 1990	new	aggr.	26 ($\sigma=5$)	26	14	11