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#### Lecture 9: The gravity equation

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#### Introduction

- In lectures 6-8, we repeatedly assessed the predictions of the models in terms of their capacity to reproduce the gravity equation
- The reason why this criteria has been extensively used is that this empirical framework is the workhorse model for analyzing bilateral trade for more than 50 years (Tinbergen, 1962)
- Krugman (1997) : Gravity equations are examples of "social physics", the relatively-few law-like empirical regularities that characterize social interactions
- Head & Mayer (2014) : Chapter 3 of the *Handbook of International Economics* on the gravity equation

# A brief history of gravity

- Tinbergen (1962) a pure empirical relationship (dismissed for its lack of theoretical underpinnings)
- Mid-90s : Admission of the gravity equation
  - Trefler (1995) : "Missing trade" which HOV fails to take into account  $\Rightarrow$  Importance of understanding the impediments to trade
  - McCallum (1995) : "Border effect" estimated in a gravity context  $\Rightarrow$  The world is NOT flat
- Since 2000, micro-fundations of the gravity equation : Eaton & Kortum (2002), Anderson & van Wincoop (2003), Chaney (2008), Melitz & Ottaviano (2008)
- Nowadays, gravity is so central that papers incorporate it as a central component of the theory (see eg Arkolakis et al, 2012)

#### Trade and the size of countries



Correlation between the Japan-EU trade and the size of partners. The x-axis measure the GDP of each EU members, in relative terms with respect to the Greek one. The y-axis measure the size of Japanese exports in each country (left-hand side) a,d the volume of Japanese imports from each country (right-hand side), again expressed in relative terms with respect to Greece. Data are for 2006. Source : Head & Mayer (2014).

• Elasticity around 1

#### Trade and distance



Correlation between the volume of trade and the distance between partners. The x-axis is the distance from France, expressed in kilometers. The x-axis measures the size of French exports (left-hand side) and the size of French imports (right-hand side), both expressed in relative terms with respect ot the destination country's GDP. Data are for 2006. Source : Head & Mayer (2014).

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# Definition

- A model of bilateral interactions in which size and distance effects enter multiplicatively (Analogy to Newton)
- General definition :

$$X_{ij} = GS_i M_j \phi_{ij}$$

with  $S_i$  exporter *i*'s "capabilities" as a supplier,  $M_j$  importer *j*'s characteristics that promote imports,  $0 \le \phi_{ij} \le 1$  bilateral accessibility, G a gravitational constant

**Key** : Third-country effects, if any, must be mediated via the i and j multilateral terms

**Note** : Multiplicative form is not crucial even though most of what we will do rely on it

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#### Definition

• Structural gravity :



where  $Y_i \equiv \sum_j X_{ij}$  (production) and  $X_j = \sum_i X_{ij}$  (consumption),  $\Omega_i$  and  $\Phi_j$  "multilateral resistance" terms :

$$\Phi_j = \sum_l rac{\phi_{lj} Y_l}{\Omega_l}$$
 and  $\Omega_i = \sum_l rac{\phi_{il} X_l}{\Phi_l}$ 

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## Definition

- Two assumptions :
  - Spatial allocation of expenditures is independent of income :

$$\pi_{ij}\equiv rac{\mathcal{X}_{ij}}{\mathcal{X}_j}=rac{\mathcal{S}_i\phi_{ij}}{\Phi_j}, \hspace{1em} ext{where} \hspace{1em} \Phi_j=\sum_l \mathcal{S}_l\phi_{lj}$$

 $\Phi_j$  the set of opportunities of consumers in j / the degree of competition in j

• Good market equilibrium :

$$Y_{i} = \sum_{j} X_{ij} = S_{i} \sum_{j} \frac{X_{j}\phi_{ij}}{\Phi_{j}} \Rightarrow S_{i} = \frac{Y_{i}}{\Omega_{i}}, \text{ where } \Omega_{i} = \sum_{l} \frac{X_{l}\phi_{il}}{\Phi_{l}}$$

 $\Omega_i$  market potential in country *i* 

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# Micro-Foundations for the gravity equation

#### **CES** National Product Differentiation

- Anderson (1979)
- Iceberg trade costs
- Armington CES utility :

$$U_{j} = \left[\sum_{i} \left(A_{i}q_{ij}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

• Gravity equation :

$$X_{ij} = \underbrace{\left(rac{w_i}{\mathcal{A}_i}
ight)^{1-\sigma}}_{\mathcal{S}_i} \underbrace{rac{X_j}{\mathcal{P}_j^{1-\sigma}}}_{M_j} \underbrace{rac{\tau_{ij}^{1-\sigma}}{\phi_{ij}}}_{\phi_{ij}}$$

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**Micro-Foundations** 

Firm-level Gravity

#### CES Monopolistic Competition

- Dixit-Stiglitz-Krugman
- Iceberg trade costs
- Armington CES utility :

$$U_j = \left[\int (q_j(\omega))^{rac{\sigma-1}{\sigma}} d\omega
ight]^{rac{\sigma}{\sigma-1}}$$

- Monopolistic competition among N<sub>i</sub> firms
- Gravity equation :

$$X_{ij} = \underbrace{\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}}_{G} \underbrace{\left(N_i \frac{w_i}{\varphi_i}\right)^{1-\sigma}}_{S_i} \underbrace{\frac{X_j}{P_j^{1-\sigma}}}_{M_i} \underbrace{\tau_{ij}^{1-\sigma}}_{\phi_{ij}}$$

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#### Heterogeneous consumers

- Anderson et al (1992)
- Assumptions
  - L<sub>j</sub> consumers of revenue w<sub>j</sub>
  - Heterogeneous in their preference over differentiated varieties :

$$u_{l(j)s(i)} = \ln[\psi_{l(j)s(i)}q_{l(j)s(i)}]$$

with  $\psi_{\mathit{l(j)s(i)}}$  an idiosyncratic preference term assumed distributed Fréchet :

$$P[\psi_{l(j)s(i)} \leq \psi] = e^{-\left(\frac{\psi}{\mathbf{A}_{i}\mathbf{a}_{ij}}\right)^{-\theta}}$$

 $\boldsymbol{\theta}$  a measure of consumer heterogeneity,  $A_i$  and  $a_{ij}$  location parameters

Iceberg trade costs

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#### Heterogeneous consumers

 $\Rightarrow$  Logit form for the probability of choosing one of the  $N_i$  varieties offered by i:

$$P_{ij} = \frac{w_i^{-\theta} A_i^{\theta} \tau_{ij}^{-\theta} a_{ij}^{\theta}}{\sum_{l} w_l^{-\theta} A_l^{\theta} \tau_{lj}^{-\theta} a_{lj}^{\theta}}$$

Probability that i offers the highest valuation for a good bought by  $\boldsymbol{j}$ 

• Gravity equation :

$$X_{ij} = \underbrace{\underbrace{N_i w_i^{-\theta} A_i^{\theta}}_{S_i}}_{S_i} \underbrace{\underbrace{\sum_{I} w_I^{-\theta} A_I^{\theta} \tau_{Ij}^{-\theta} a_{Ij}^{\theta}}_{M_j}}_{M_j} \underbrace{\tau_{ij}^{-\theta} a_{ij}^{\theta}}_{\phi_{ij}}$$

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#### Heterogeneous Industries

- Eaton & Kortum (2002)
- Assumptions
  - A continuum of "industries" heterogeneous in productivities

$$P[z_i \leq z] = e^{-T_i z^{-\theta}}$$

- Perfect competition across countries
- Iceberg trade costs
- Gravity equation :

$$X_{ij} = \underbrace{T_i w_i^{-\theta}}_{S_i} \underbrace{\frac{X_j}{\sum_l T_l w_l^{-\theta} \tau_{lj}^{-\theta}}}_{M_i} \underbrace{\tau_{ij}^{-\theta}}_{\phi_{ij}}$$

#### Heterogeneous Firms

- Melitz (2003) + Chaney (2008)
- Assumptions
  - A continuum of firms heterogeneous in productivities
  - Monopolistic (DS) competition across firms and countries
  - Iceberg trade costs
- Gravity equation :

$$X_{ij} = \underbrace{\underbrace{N_i w_i^{1-\sigma}}_{S_i}}_{S_i} \underbrace{\underbrace{\sum_{l} N_l w_l^{1-\sigma} \tau_{lj}^{1-\sigma} \tilde{\varphi}(\varphi_{lj}^*)^{\sigma-1}}_{M_j}}_{M_j} \underbrace{\tau_{ij}^{1-\sigma} \tilde{\varphi}(\varphi_{ij}^*)^{\sigma-1}}_{\phi_{ij}}$$

• With a Pareto distribution of productivities  $(G(\varphi) = 1 - \varphi^{-\theta})$ :

$$X_{ij} = \underbrace{N_i w_i^{1-\sigma}}_{S_i} \underbrace{\frac{X_j}{\sum_l N_l w_l^{1-\sigma} \tau_{lj}^{-\theta} f_{lj}^{-\left[\frac{\theta}{\sigma-1}-1\right]}}_{M_j}}_{M_j} \underbrace{\tau_{ij}^{-\theta} f_{ij}^{-\left[\frac{\theta}{\sigma-1}-1\right]}}_{\phi_{ij}}$$

#### Implications for the interpretation of results

- In the 80s, gravity is dismissed for its lack of theoretical foundations. Now, there are almost too much models which are consistant with gravity !
- While various models deliver gravity, interpretation is VERY different across models
  - In CES model,  $\frac{d \ln X_{ij}}{d \ln \tau_{ij}} = -(\sigma 1)$ , a demand parameter
  - In the context of heterogeneous consumers,  $\frac{d \ln X_{ij}}{d \ln \tau_{ij}} = -\theta$ , a demand parameter
  - In the heterogeneous industries model,  $\frac{d \ln X_{ij}}{d \ln \tau_{ij}} = -\theta$ , a supply parameter
  - In the heterogeneous firms model,  $\frac{d \ln X_{ij}}{d \ln \tau_{ij}} = -\theta$  and  $\frac{d \ln X_{ij}}{d \ln f_{ij}} = -\left[\frac{\theta}{\sigma 1} 1\right]$ , combination of demand and supply parameters

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# **Theory-Consistent Estimation**

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#### Empirical challenges

- Historically, gravity equations were using as RHS variables the countries' GDP, populations and bilateral measures of barriers to trade
- This does not control for the "multilateral resistance terms"  $(\Phi_j \text{ and } \Omega_i)$  which creates a bias (Anderson & van Wincoop, 2003)
- Various solutions have been proposed in the literature

#### Proxies for multilateral Resistance Terms

 Log-GDP-weighted average distance (Wei, 1996, Baldwin & Harrigan, 2011) :

$$\textit{Remoteness}_j = \left(\sum_i rac{m{Y}_i}{\textit{Dist}_{ij}}
ight)$$

Larger for countries that are closer to large countries More or less consistent with the theory if  $\phi_{ij} = Dist_{ij}^{-1}$ ,  $X_j = Y_j$  and thus  $\Phi_j = \sum_k \frac{Y_l}{Dist_{ij}} \Omega_l^{-1}$  and  $\Omega_i = \sum_l \frac{Y_l}{Dist_{il}} \Phi_l^{-1}$ 

Iterative structural estimation (Head & Mayer, 2014) :
 i) Assumes Ω<sub>i</sub> = 1 and Φ<sub>j</sub> = 1, ii) Estimates the model to recover the parameters determining φ<sub>ij</sub>, iii) Given those parameters, compute new Ω<sub>i</sub>s and Φ<sub>j</sub>s, iv) Iterate until the parameters stop changing

#### Fixed effect estimations

• Fixed effect specification :

$$\ln X_{ij} = \ln G + \ln S_i + \ln M_j + \ln \phi_{ij}$$

Note : In panel data,  $S_i$  and  $M_j$  should also have a time-dimension. In sectoral data, they should also have the industry dimension (high-dimensional fixed effect model)

• Ratio-type estimation : To get rid of some fixed effects, take ratios :

$$\begin{split} \frac{X_{ij}}{X_{jj}} &= \frac{S_i}{S_j} \frac{\phi_{ij}}{\phi_{jj}}, \quad \frac{X_{ij}/X_{ik}}{X_{lj}/X_{lk}} = \frac{\phi_{ij}/\phi_{ik}}{\phi_{lj}/\phi_{lk}} \\ \frac{X_{ij}}{X_{ji}} \frac{X_{ji}}{X_{ii}} &= \frac{\phi_{ij}\phi_{ji}}{\phi_{ji}\phi_{ii}} \Rightarrow \phi_{ij} = \sqrt{\frac{X_{ij}X_{ji}}{X_{ii}X_{jj}}} \text{ if } \phi_{ij} = \phi_{ji} \text{ and } \phi_{ii} = 1 \\ \frac{X_{ij}X_{jk}X_{ki}}{X_{ji}X_{kj}X_{ik}} &= \left(\frac{(1+t_{ij})(1+t_{jk})(1+t_{ki})}{(1+t_{ji})(1+t_{kj})(1+t_{ki})}\right)^{\epsilon} \end{split}$$

where  $(1 + t_{ij})$  is the asymmetric component of trade costs

#### Zeros in Trade Matrices

- Up to now, we have systematically considered gravity equations which are solely defined for strictly positive trade flows
- Helpman et al (2008) : Even at the country level, about half the observations in the typical trade matrix are zeros
- The problem gets even worse in more disaggregated data
- How can models / estimation methods take this into account?
- Theoretical tricks : Truncate the productivity distribution (Helpman et al, 2008), Abandon the assumption of a continuum of firms (Eaton et al, 2012). Since zeros are more likely across distance/costly country pairs, neglecting those zeros will systematically underestimate the impact of distance

#### Proposed solutions

- Use  $ln(1 + X_{ij})$  as LHS variable : A bad idea ! Sensitive to units
- Eaton and Kortum (2001) : Estimate a Tobit model where the LHS variable is defined as  $\ln X_{ij}^*$  where  $X_{ij}^* = X_{ij}$  for all positive trade flows and  $X_{ij}^* = \underline{X}_{ij}$  whenever  $X_{ij} = 0$ .  $\underline{X}_{ij}$  defined as the minimum value of trade for a given *j*. Amounts to assume that missing values are trade flows which fall below a declaration threshold
- Helpman et al (2008) : Heckman-based approach : i) probit to estimate the probability of  $X_{ij} > 0$  and ii) OLS gravity equation on positive trade flows including a selection correction. Exclusion restriction : Overlap in religion and product of dummies for low entry barriers in countries *i* and *j*...
- Eaton et al (2012) : Multinomial PML deal with the zeros induced

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# **Gravity Estimates**

#### Meta-Analysis Results

$$\begin{aligned} \ln X_{ij} &= \alpha_1 \ln Y_i + \alpha_2 \ln Y_j + \alpha_3 \ln Dist_{ij} + \alpha_4 \mathbf{1}_{Contiguity_{ij}} + \alpha_5 \mathbf{1}_{CommonLanguage_{ij}} \\ &+ \alpha_6 \mathbf{1}_{ColonialLink_{ij}} + \alpha_7 \mathbf{1}_{RTA/FTA_{ij}} + \alpha_8 \mathbf{1}_{EU_{ij}} + \alpha_9 \mathbf{1}_{NAFTA_{ij}} \\ &+ \alpha_9 \mathbf{1}_{CommonCurrency_{ij}} + \alpha_{10} \mathbf{1}_{Home_{ij}} + \varepsilon_{ij} \end{aligned}$$

	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.

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#### Meta-Analysis Results

- Average distance effect around -1.1
- Contiguity and common language effects around .5 (+65% of trade conditional on sharing a border or the same language).
   Colonial linkages imply larger effects (+130%)
- Some uncertainty regarding the impact of RTAs but NAFTA seems to have larger effects
- Estimates on common currency imply a doubling of trade, on average. Lower than the initial estimates by Rose (2000) who found a tripling of trade. Note that this does not control for the endogeneity of currency or trade unions
- Home bias is still huge, +370%

#### Distance elasticity, over time



- Doubling the distance reduces trade by a factor of two
- Interpretation : Transportation costs, "Time as a trade barrier", Cultural distance, Informational frictions
- Over time, trade becomes more geographically concentrated !

### Partial vs General Equilibrium Impacts of trade

• Impact of changing trade barriers :

$$\frac{X'_{ij}}{X_{ij}} = \underbrace{\frac{\phi'_{ij}}{\phi_{ij}}}_{Direct} \underbrace{\frac{\Omega_i}{\Omega'_i} \frac{\Phi_j}{\Phi'_j}}_{MR \ Adj.} \underbrace{\frac{Y'_i}{Y_i} \frac{X'_j}{X_j}}_{GDP \ Adj.}$$

- Direct impact :  $exp[\hat{\alpha}_i(B'_{ij} B_{ij})]$
- Impact on multilateral indices : Usually negative. eg signing an RTA between *i* and *j* implies a decrease in  $\tau_{ij}$  (an increase in  $\phi_{ij}$ ). Because RTA makes access to *j* easier, competition gets fiercer and raises  $\Phi_j$ . This counteracts the direct effect of a raise in  $\phi_{ij}$  and transmit the impact of the shock on all the  $X_{i'j}$  terms
- Impact on GDPs
- ⇒ Obtained through simulations

#### Partial vs General Equilibrium Impacts of trade

#### Table 3.6 PTI, MTI, GETI, and Welfare Effects of Typical Gravity Variables

	Coeff.	ΡΤΙ	МТІ		GETI		Welfare	
Members:	Yes	Yes	Yes	No	Yes	No	Yes	No
RTA/FTA (all)	.28	1.323	1.129	.946	1.205	.96	1.011	.998
EU	.19	1.209	1.085	1.007	1.136	1.001	1.013	.999
NAFTA	.53	1.699	1.367	1.005	1.443	1	1.048	1
Common currency	.98	2.664	1.749	1.028	2.203	1.003	1.025	.998
Common language	.33	1.391	1.282	.974	1.303	.99	1.005	.999
Colonial link	.84	2.316	2.162	.961	2.251	.984	1.004	.999
Border effect	1.55	4.711	4.647	.938	3.102	.681	.795	n/a

Notes: The MTI, GETI, and welfare are the median values of the real/counterfactual trade ratio for countries relevant in the experiment.

- MTI usually smaller than PTI
- GETI close to MTI except for large shocks like removing the border
- Welfare impact is usually small (see Lecture 10) <=> <=> = ∽०० <

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# Firm-level gravity

#### Motivation

- The increasing availability of firm-level data makes it possible to estimate separately the response of trade to shocks along the intensive and extensive margins
- Proposed decompositions :

$$\begin{array}{ll} \frac{\partial \ln X_{ij}}{\partial \ln \tau_{ij}} &=& \frac{\partial \ln N_{ij}}{\partial \ln \tau_{ij}} + \frac{\partial \ln \bar{x}_{ij}}{\partial \ln \tau_{ij}} \\ &=& \underbrace{\frac{\partial \ln N_{ij}}{\partial \ln \tau_{ij}}}_{Ext.Margin} + \underbrace{\frac{1}{\bar{x}_{ij}} \left( \int_{\phi_{ij}^*}^{+\infty} \frac{\partial \ln x_{ij}(\varphi)}{\partial \ln \tau_{ij}} x_{ij}(\varphi) \frac{g(\varphi)}{1 - G(\varphi_{ij}^*)} d\varphi \right)}_{Int.Margin} \\ &+& \underbrace{\frac{-\partial \ln G(\varphi_{ij}^*)}{\partial \ln \varphi_{ij}^*} \frac{\partial \ln \varphi_{ij}^*}{\partial \ln \tau_{ij}} \left( \frac{x_i j(\varphi_{ij}^*)}{\bar{x}_{ij}} - 1 \right)}_{Comp.Effect} \end{array}$$

Extensive margin is the elasticity of the number of exporters to the change in trade cost

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#### CES-Iceberg model

• Intensive margin :

$$x_{ij}(\varphi) = \left(\frac{\sigma}{\sigma - 1} \frac{w_i \tau_{ij}}{\varphi}\right)^{1 - \sigma} \frac{X_j}{\Phi_j} \Rightarrow \frac{\partial \ln x_{ij}(\varphi)}{\partial \ln \tau_{ij}} = 1 - \sigma$$

• Extensive margin :

$$N_{ij} = (1 - G(\varphi_{ij}^*))N_i \Rightarrow \frac{\partial \ln N_{ij}}{\partial \ln \tau_{ij}} = -\frac{\partial \ln G(\varphi_{ij}^*)}{\partial \ln \varphi_{ij}^*} \underbrace{\frac{\partial \ln \varphi_{ij}^*}{\partial \ln \tau_{ij}}}_{1}$$

• Composition effect :

$$\frac{-\partial \ln {\sf G}(\varphi_{ij}^*)}{\partial \ln \varphi_{ij}^*} \left(\frac{{\sf x}_i j(\varphi_{ij}^*)}{\bar{\sf x}_{ij}}-1\right)$$

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#### CES Iceberg model

Thus :



• With Pareto :



Composition exactly compensates the intensive margin

#### Intensive and extensive gravity

# Figure: The intensive & extensive components of the gravity equation (Crozet & Koenig, Table 2)

	All fir	ms	Single-region firms			
	> 20  emp	loyees	> 20 employees			
	(1)	(2)	(3)	(4)		
	Average	Number of	Average	Number of		
	Shipment	Shipments	Shipment	Shipments		
	$\ln (M_{kjt}/N_{kjt})$	$\ln (N_{kjt})$	$\ln (M_{kjt}/N_{kjt})$	$\ln (N_{kjt})$		
$\ln (GDP_{kj})$	$0.461^{a}$	$0.417^{a}$	$0.421^{a}$	$0.417^{a}$		
	(0.007)	(0.007)	(0.007)	(0.008)		
$\ln (\text{Dist}_i)$	$-0.325^{a}$	$-0.446^{a}$	$-0.363^{a}$	$-0.475^{a}$		
	(0.013)	(0.009)	(0.012)	(0.009)		
Contig <sub>i</sub>	-0.064 <sup>c</sup>	-0.007	0.002	$0.190^{a}$		
	(0.035)	(0.032)	(0.038)	(0.036)		
Colony <sub>j</sub>	$0.100^{a}$	$0.466^{a}$	$0.141^{a}$	$0.442^{a}$		
-	(0.032)	(0.025)	(0.035)	(0.027)		
French <sub>j</sub>	$0.213^{a}$	$0.991^{a}$	$0.188^{a}$	$1.015^{a}$		
-	(0.029)	(0.028)	(0.032)	(0.028)		
N	23553	23553	23553	23553		
$R^2$	0.480	0.591	0.396	0.569		

Note: These are OLS estimates with year and industry dummies. Robust standard errors in parentheses with <sup>a</sup>, <sup>b</sup> and <sup>c</sup> denoting significance at the 1%. 5% and 10% level respectively.

• Extensive margin accounts for 57% of the distance effect. Larger share in other studies

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### Conclusion

- Nowadays, gravity is both a successful empirical model and a benchmark which guides theoretical modeling
- Gravity equation has also been used in other contexts, with some success :
  - Service offshoring (Head et al, 2009),
  - Migrations (Anderson, 2011),
  - Commuting (Ahlfeldt et al, 2014),
  - Portfolio investments (Portes et al, 2001),
  - FDI (Head & Ries, 2008)

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