Trade, Size, and Frictions: the Gravity Model

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Why So Little Trade?

Trade is tiny relative to potential. Some patterns:

- Big countries trade more (e.g. US and China) but small ones appear more open (e.g. Belgium).
- Distance and borders apparently kill of a lot of trade, given relative country size.
- T. Friedman's "the world is flat" is hugely wrong — world trade is $<$ 10% of potential.

The gravity model organizes these striking regularities.

Gravity explains multi-country interactions. (Intuitively, the more country A trades with country B, the less is left over for trade with country C. Frictions between B and C thus affect A's trade with either B or C.)

More Applications of Gravity

Gravity applies within countries, regions (and even within institutions such as BC). Remarkably, seems to apply at any scale.

Gravity pplies to migration (first use in fact, in 1880s UK) and foreign direct investment patterns.

Gravity used for inference of barriers to trade.

1 International Trade

Map of World Trade

FIGURE 1-1

World Trade in Goods, 2006 ($ billions) Trade in merchandise goods between selected countries and regions of the world.

Figure 1: Trade is proportional to size

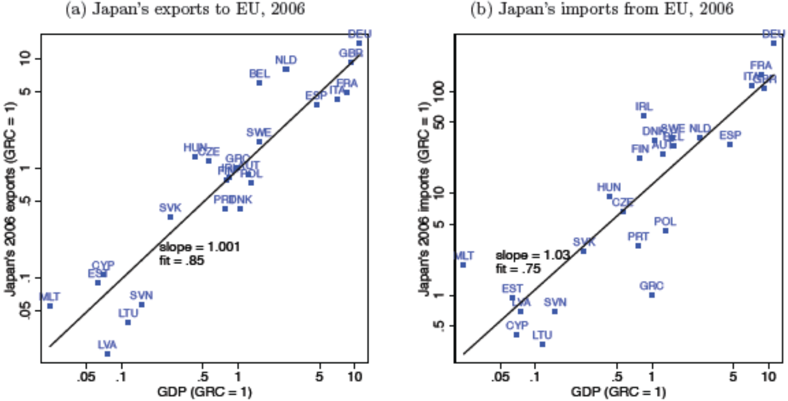
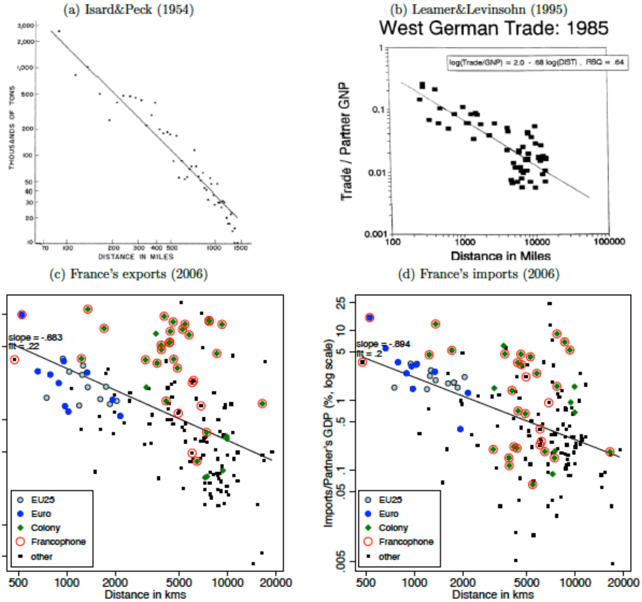


Figure 2: Trade is inversely proportional to distance



1 International Trade

Trade Compared with GDP

TABLE 1-2

Trade/GDP Ratio in 2008 **Countries with the highest ratios of trade to GDP tend to be small in economic size. Countries with the lowest ratios of trade to GDP tend to be very large in economic size.**

Country	Trade/GDP (%)	GDP ($ billion)	Country	Trade/GDP (%)	GDP ($ billion)	Country	Trade/GDP (%)	GDP ($ billion)
Hong Kong, China	207%	215%	South Africa	37	276	Turkey	26	735
Malaysia	116	222	Canada	33	1,501	Russian Federation	26	1,679
Hungary	81	155	China	33	4,327	Venezuela	25	314
Thailand	75	272	United Kingdom	30	2,674	India	25	1,159
Switzerland	65	492	Indonesia	29	511	Argentina	23	328
Austria	56	414	Italy	29	2,303	Pakistan	18	165
Denmark	54	341	Mexico	29	1,088	Japan	16	4,911
Sweden	50	479	Spain	29	1,604	United States	15	14,093
Germany	44	3,649	Greece	28	356	Brazil	14	1,575
Norway	38	452	France	28	2,857			

Size and Trade Summary Observations

- bilateral trade rises with the size of either trading partner
- countries further apart trade less
- borders appear to impede trade a lot

The gravity model explains these patterns.

Frictionless World Benchmark

Size has a lot of explanatory power. Bigger incomes buy more from everywhere; bigger sales sell more to everywhere.

Developing a model where size *alone* determines trade patterns is thus useful in abstracting from complex frictions.

A particularly important use for such a model is to provide a *benchmark* for what a frictionless world would look like.

Frictionless Gravity Model

Assume:

- demand at each destination for goods from all origins
- market clearance
- perfect arbitrage with, for now, no trade costs

Expenditure by j is E_j; sales of i is Y_i; world sales is Y.

In a completely smooth homogenized world, the exports flow from i to j, X_{ij} is given by:

$$\frac{X_{ij}}{E_j} = \frac{Y_i}{Y} \Rightarrow X_{ij} = \frac{Y_i E_j}{Y} \qquad (1)$$

Equation (1) $\Rightarrow$ the share of j's expenditure on goods from i is equal to the share of world expenditure ($=$ sales) on goods from i. Figure 1 says (1) fits well, X_{ij} proportional to E_j. Natural frictionless benchmark.

Frictionless Gravity Equilibrium

Market clearance (material balance) implies that

$$\sum_j X_{ij} = Y_i. \tag{2}$$

World budget constraint $\Rightarrow \sum_j E_j = \sum_i Y_i = Y$. Thus (1) is consistent with market clearance: check by summing right hand side of (1) over j and using the world budget constraint to set $\sum_j E_j/Y = 1$.

If we impose a no net trade budget constraint for each country then $E_i = Y_i$, hence $X_{ij} = Y_i Y_j/Y$, but the more general specification (1) is far more realistic.

Implications of Frictionless Gravity

Define $s_i = Y_i/Y$, country i's share of world sales, and $b_i = E_i/Y$, country i's share of world expenditure. Assume balanced trade for now, $b_i = s_i$. Then:

$$X_{ij} = s_i s_j Y.$$

Implications

1. Any country trades more with bigger partners.
2. Smaller countries are more naturally open:

   $$\sum_{i \neq j} X_{ij}/Y_j = 1 - s_j$$

   which is decreasing in s_j.
3. Faster growing country pairs have increasing share of world trade: $X_{ij}/Y = s_i s_j$ is increasing in s_i, s_j.

Aside on Growth Rate Accounting

Point 3 on the previous slide uses a basic property of growth rate accounting.

Let $\widehat{x}$ denote the growth rate of x. Then (the Hat Rule)

$$x = y/z \Rightarrow \widehat{x} = \widehat{y} - \widehat{z}$$

and

$$x = yz \Rightarrow \widehat{x} = \widehat{y} + \widehat{z}.$$

Thus the rate of growth of X_{ij}/Y is equal to $\widehat{s}_i + \widehat{s}_j$. And $\widehat{s}_i = \widehat{Y}_i - \widehat{Y}$.

The Hat Rule follows from log differentiation:
$d \ln y/z = d \ln y - d \ln z = \widehat{y} - \widehat{z}$.

Evidence of Frictions

Trade is much smaller than indicated by (1). US has 25 percent of world GDP, exports should be 75 % of GDP vs. 10-15 % actual. ($X_{US,ROW}/Y_{US} = E_{ROW}/Y = 0.75$)

- Trade falls sharply with distance (with effect D_{ij} reflecting distance between i and j):

$$X_{ij} = \frac{Y_i E_j}{Y} \frac{1}{D_{ij}}. \tag{3}$$

  (3) gives a pretty good fit with actual trade data (viz. Figure 2). Implication: doubled distance $\Rightarrow$ halved trade.
- Crossing borders further reduces trade a lot. i.e., $D_{ij} = d_{ij} B_{ij}$ where $B_{ij} > 1 = B_{ii}$ for $i \neq j$ in equation (3) is the effect of a border between i and j and d_{ij} is distance.

Economic Theory of Gravity

Equation (3) or its variants allowing for borders and other effects was inspired by Newton's Law of Gravity (where $D_{ij} = d_{ij}^2$, the square of bilateral distance between i and j, Y_i is mass at i and $1/Y$ is the gravitational constant). Thus it is called the gravity equation or model. It has no economic theory behind it.

Economic theory leads to an expenditure share called structural gravity. (It is derived from one of three well justified foundations.)

$$\frac{X_{ij}}{E_j} = \frac{Y_i}{Y} \left(\frac{D_{ij}}{\Pi_i P_j} \right)^{1-\sigma}, \tag{4}$$

where $\sigma > 1$, hence $1 - \sigma < 0$.

Behind the Share Equation

The intuitive meaning of (4) is that bilateral trade falls as the 'economic distance' between origin and destination rises. Equation (4) restricts the responsiveness to a constant elasticity $1 - \sigma, \sigma > 1$. [For the derivation see Anderson (2011).]

Equation (4) is linear in logarithms — suggests fitting a straight line on data points relating log trade shares to log distance. The slope is $1 - \sigma$ to be inferred.

Essentially this is the empirical procedure used. But complicated by needing multivariate inference. Π_i and P_j act on the bilateral trade flow data as common exporter and importer country shifters (fixed effects to be inferred).

Economic Theory of Gravity

Repeating the share equation (4)

$$\frac{X_{ij}}{E_j} = \frac{Y_i}{Y}\left(\frac{D_{ij}}{\Pi_i P_j}\right)^{1-\sigma}.$$

The right hand side of share equation is in two parts. Y_i/Y is the frictionless expenditure share prediction. $\left(D_{ij}/\Pi_i P_j\right)^{1-\sigma}$ is the effect of trade frictions.

Π_i is the appropriate 'average' portion of trade costs borne by seller *i* to *all* destinations, outward multilateral resistance. P_j is the appropriate average portion of trade costs borne by buyer *j* from all sources, inward multilateral resistance.

Π_i and P_j are not observable but can be inferred along with D_{ij}.

Behind the Share Equation, 2

While share equation (4) is certainly quite special, it is more general than it at first appears.

The three theoretical justifications for (4) are:

1. consumers (producers) gain from variety of goods consumed (used in production)
2. consumers (producers) differ in their ideal varieties, characterized by a probability distribution, and equation (4) gives the proportion of buyers who prefer the variety of region i.
3. consumers want only one variety of any good but there are many goods and producers differ in their productivities, characterized by a probability distribution. The shares in equation (4) refer to proportions of all goods produced by i and sold to j.

Gravity, Migration and Investment

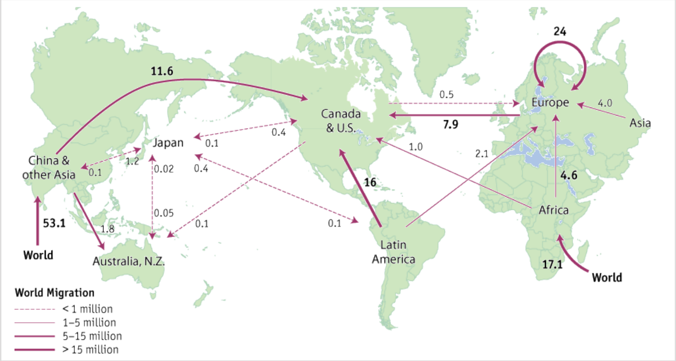
The gravity model can also be applied to migration of labor and to foreign direct investment. The same structure yields similarly good fit with data. The theoretical underpinnings change a bit in details that do not matter for many purposes.

Gravity also tends to explain portfolio investment (cross country ownership of stocks and bonds) but here the theory base is lacking.

2 Migration and Foreign Direct Investment

Map of Migration

FIGURE 1-3



Foreign-Born Migrants, 2005 (millions)

This figure shows the number of foreign-born migrants living in selected countries and regions of the world for 2005 in millions of people.

Empirical Gravity

Example: econometric inference of coefficients δ, b in assumed function:

$$D_{ij} = d_{ij}^{\delta} b^{b_{ij}} \tag{5}$$

where d_{ij} is the distance between i and j, $b_{ij} = 1$ if there is a border between i and j and $b_{ij} = 0$ if there is no border (inter- or intra-regional trade). $b > 0$ is the border resistance. It can be identified when shipments data includes internal as well as external trade.

Specification (5) makes the border resistance the same for all countries, but this can be relaxed to allow variation by country and also by direction of trade.

More elaborate versions of (5) allow for language differences, contiguity, former colonial ties, etc.

Inference

Infer best fitting coefficients δ, b along with Π_i and P_j from

$$\frac{X_{ij}}{Y_i E_j / Y} = \left(\frac{d_{ij}^{\delta} b^{bij}}{\Pi_i P_j} \right)^{1-\sigma} \epsilon_{ij} \qquad (6)$$

where ϵ_{ij} is the random error term representing the forces not explained by the model.

Estimated equations like (6) usually “explain" 90% of the variation in trade. Coefficients are precisely estimated.

Coefficient $1 - \sigma$ can be inferred if some trade cost is directly observed. Otherwise, distance elasticity $\delta(1 - \sigma)$ is inferred, for example. σ itself is not needed for many purposes.

Inference, 2

$\delta(1-\sigma)$ *et al.* coefficients are inferred. Distance elasticities $\delta(1-\sigma) \approx -1$ typically.

Border effects $-3 \leq (1-\sigma)\ln b \leq -1$ typically.

$1-\sigma$ can be inferred if some trade cost element of D_{ij} is directly observed. Typically $10 > \sigma > 6$.

Distance elasticity varies depending on distance range: empirical results show mostly higher for shorter distance ranges.

Structural Gravity Implications

Use the estimated coefficients to form the ratio of predicted (indicated by a tilde) to predicted frictionless trade:

$$\frac{\widetilde{X}_{ij}}{Y_i E_j / Y} = \left(\frac{\widetilde{D}_{ij}}{\widetilde{\Pi}_i \widetilde{P}_j} \right)^{1-\sigma} \qquad (7)$$

A particularly interesting instance of (7) is for internal trade, $i = j$. This is Constructed Home Bias, the predicted excess (relative to frictionless) amount of local trade.

$$CHB_i = \left(\frac{\widetilde{D}_{ii}}{\widetilde{\Pi}_i \widetilde{P}_i} \right)^{1-\sigma} \qquad (8)$$

Home Bias

Most all countries' international trade is far less than predicted by frictionless benchmark. For example, US has 25% of world GDP, frictionless export share should be 75% vs. actual share $\approx$ 10%.

Openness to trade is associated with gains from trade (to be demonstrated subsequently). CHB is a measure of foregone potential gains.

Conversion of CHB to a welfare measure requires estimate of trade elasticity $1 - \sigma$, emphasized in Arkolakis, Costinot & Rodriguez-Clare (AER, 2012).

CHB in Manufacturing

Using manufacturing trade and production data for 76 countries from 1990-2002, Anderson and Yotov (2011) estimate CHBs.

The results below add another major implication about the relationship of size and trade: *While bigger producers trade less in the frictionless benchmark, they tend to trade more (a lot more) relative to the frictionless benchmark*.

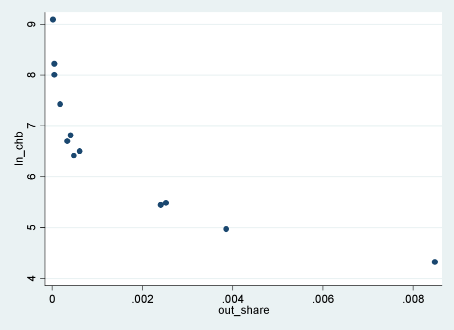
- CHB is very large
- CHB is (much) lower for bigger producers
- the lower CHB is due almost entirely to lower Π, interpretable as sellers' incidence of trade costs.
- falling (rising) CHB over time is due to falling (rising) Π, associated with increasing (decreasing) sales shares Y_i/Y.
- lower Π is equivalent to productivity improvement

Table: Constructed Home Bias Indexes by Country

Countries with Lowest CHB			Countries with Highest CHB		
ISO	1996	$\%\Delta CHB$	ISO	1996	$\%\Delta CHB$
USA	3	-11	MUS	658	-37
JPN	5	41	LVA	679	-43
DEU	8	0	CRI	694	-33
FRA	11	2	EST	704	-54
CHN	12	-51	AZE	737	154
ITA	13	-14	BOL	778	-5
GBR	14	15	JOR	866	-28
CAN	19	0	PAN	872	-15
HKG	20	-22	OMN	948	-49
KOR	20	-28	SLV	1186	-54
ESP	25	-2	MDA	1224	24
BRA	32	56	TZA	1254	-28
MYS	36	-52	MNG	1328	139
BLX	37	30	SEN	1336	-5
NLD	39	24	TTO	1577	-58
RUS	39	33	ARM	2423	-39
AUT	41	13	KGZ	2554	276
IND	44	-13	MOZ	2630	-44

Size and CHB in Services Trade

Plot ln CHB_i vs. Y_i/Y, Canada's provinces (Anderson, Milot and Yotov, 2011).



Size and Sellers' Incidence

Multilateral resistance is interpreted as average incidence: outward for sellers Π_i, and inward for buyers P_j for each i and j.

Why does Π get smaller as size gets larger?

- A big country has less of its total shipments forced into crossing borders (as in the frictionless model), so it incurs less trade cost on average on its shipments $\Rightarrow$ lower sellers' incidence of trade costs.
- This is a tendency only, not a one-to-one relationship. Statistically close relationship in the sense of high negative correlation.

An important force acting as if economies of scale, even though no economies of scale in model.

Size and Trade Again

Summarizing the key insights from the gravity literature:

1. Any country naturally trades more with bigger partners.
2. Smaller countries are more naturally open.
3. Faster growing country pairs have increasing share of world trade
4. Given natural openness, bigger countries tend to trade much more because they tend to have much lower Constructed Home Bias.
5. Bigger countries lower CHB due mostly to lower outward multilateral resistance $=$ sellers' incidence.

Projections

A valuable use of the empirical gravity model is to project missing data.

- Use estimated gravity coefficients (estimated using other data and (7)) to calculate

$$\frac{Y_i E_j}{Y}\left(\frac{d_{ij}^{\delta} b^{b_{ij}}}{\Pi_i P_j}\right)^{1-\sigma} = \widetilde{X}_{ij}.$$

- Can be used to check or replace bad or suspicious data (e.g. smuggling)
- Used to forecast effects of big changes — e.g., fall of Iron Curtain on E. European countries.
- Can be used to forecast effects of building a canal, bridge, etc.

What Are “Trade Costs"?

Frictions implied by gravity are way bigger than can be explained by measured trade costs. (See Anderson & van Wincoop JEL survey, 2004.)

A number of possible explanations for ‘dark’ trade costs:

- information costs
- non-monetary barriers — regulation, licensing,...
- taste differences
- extortion, insecure contracts

Need to drill deeper to understand these forces.

Mystery of Missing Globalization

Estimation of gravity coefficients on various datasets yields no recent evidence of decreasing coefficients on distance (or other frictions such as borders).

One answer to the puzzle is that if all trade costs (distance) shrink(s) uniformly, all relative trade costs (distances) t_{ij}/t_{kl} (d_{ij}/d_{kl}) remain the same $\Rightarrow$ constant relative trade X_{ij}/X_{kl}. Thus no decrease in the distance coefficient would be found in estimated gravity equations across time, even though the world was ‘getting smaller’.

Uniformity hypothesis is roughly plausible: better shipping and communications stimulate trade within as well as between countries.

Direct Measures of Trade Cost Changes

Recent data on changes over time in trade costs:

- sea freight rates have risen (container rates) but quality is much better (containerization). See M. Levinson *The Box*.
- Some freight has shifted from surface to air.
- Observed willingness-to-pay difference is lower bound estimate of quality improvement. Further effects of quality change may be large.
- Tariffs fell most among big countries in the 50s through 70s, so not much recent action there.
- end of Multi-Fibre Arrangement is much more significant for textiles and apparel.
- some regulatory agreements have fostered trade, especially in services.
- Free Trade Agreements seem to foster trade much more than implied by the tariff cuts.

Globalization and Specialization

World trade T is rising (except for the 2008 sharp recession) relative to value of world shipments Y, good by good and overall. What is the explanation, if gravity coefficients are constant?

- measurement of constant gravity coefficients may be wrong.
- production/expenditure patterns shifting may induce trade-increasing changes. *Specialization* may explain the changing location of production.

Work is proceeding on both points.