Technology, Geography, and Trade

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Goal

- Develop a model incorporating realistic geographic features into General Equilibrium
- Derive structural equations for bilateral trade
- Estimate parameters of the model
- Counterfactuals

- Eaton and Kortum are not the first to give the gravity equation a structural interpretation.

- Helpman (1987)
  assumes monopolistic competition with firms in different countries choosing to produce differentiated products. Implication is that each source should export a specific good everywhere.

  Haveman and Hummels (2002) report evidence to the contrary.

- In Eaton and Kortum (2002), more than one country may produce the same good, with individual countries supplying different parts of the world.

Model

- Building on Dornbusch, Fischer, Samuelson (1977) model of Ricardian trade with a continuum of goods, 2 country model only.
- Countries have differential access to technology, efficiency varies across commodities and countries.
- Denote country i's efficiency in producing good $j \in [0,1]$ as $z_i(j)$.
- Denote input cost in country i as c_i

(Later c will be broken into the cost of labor and of intermediate inputs).

- Cost of a bundle of inputs is the same across commodities within a country (because country inputs are mobile across activities and activities do not differ in their input shares).

- With CRS, the cost of producing a unit of good j in country i is $\frac{c_i}{z_i(j)}$.

- Geographic barriers: Iceberg transportation cost, delivering a unit from country i to country n requires producing d_{ni} units in i, (d_{ii}=1 for all i, $d_{ni} > 1$ for $n \neq i$.).

- Assume the triangle inequality, for any 3 countries i, k and n holds: $d_{ni} \leq d_{nk} \cdot d_{ki}$.

- Delivering a unit of good j produced in country i to country n costs: $p_{ni}(j) = \left(\dfrac{c_i}{z_i(j)} \right) \cdot d_{ni}$
- Perfect Competition: $p_{ni}(j)$ is what buyers in country n would pay if they chose to buy good j from country i.
- Shopping around the world for the best deal, yields price of j:

$$p_n(j) = \min\left\{ p_{ni}(j), i = 1, \ldots N \right\},$$

where N is the number of countries.

- Facing these prices, buyers (final consumers or firms buying intermediate inputs) purchase goods in amounts Q(j) to max CES objective:

$$U = \left[\int_0^1 Q(j)^{\frac{\sigma-1}{\sigma}} dj \right]^{\frac{\sigma}{\sigma-1}}$$

where σ>0 is the elasticity of substitution.

- Maximization is subject to a budget constraint. It aggregates across buyers in country n to X_n, country n's total spending.

- Probabilistic representation of technologies: country i's efficiency in producing good j is the realization of a random variable Z_i.
- Z_i is drawn independently for each j from its country specific distribution: $F_i(z) = \Pr[Z_i \leq z]$.
- The cost of purchasing a particular good from country i in country n is the realization of the random variable:

$$P_{ni}(j) = \left(\frac{c_i}{Z_i}\right) \cdot d_{ni}$$

- The lowest price is the realization of:

$$P_n(j) = \min\left\{P_{ni}; i = 1, \ldots. N\right\}.$$

- π_{ni} is the probability that country i supplies a particular good to country n (probability that i's price turns out to be the lowest).

- Probability theory of extremes provides a form for $F_i(z)$ that yields a simple expression for π_{ni} and for the resulting distribution of prices.

Aside:

- Kortum (1997) and Eaton and Kortum (1999) show how a process of innovation and diffusion can give rise to Frechet distribution, with T_i reflecting a country's stock of original or imported ideas.

- Since the actual technique that would ever be used in any country represents the best discovered to date for producing each good, it makes sense to represent technology with an extreme value distribution.

- The distribution of the maximum of a set of draws can converge to one of only three distributions:

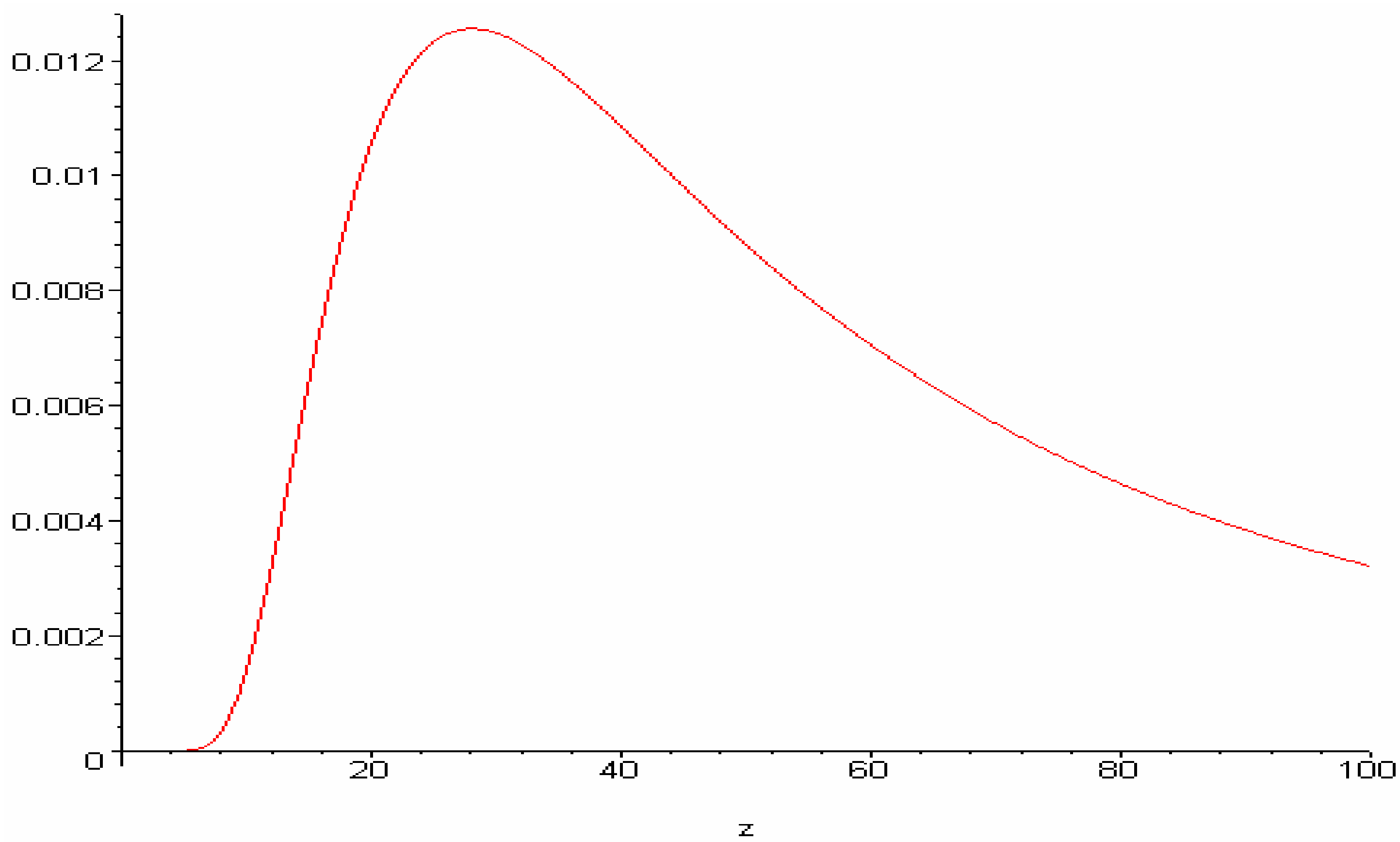
- the Weibull
- the Gumbell
- the Frechet

Only for Frechet does the distribution of prices inherit an extreme value distribution.

Therefore it was chosen.

Frechet distribution: $F_i(z) = e^{-T_i \cdot z^{-\theta}}$, where T_i>0 and **q**>1.

Theta=1.2
T=100



$F_i(z) = e^{-T_i \cdot z^{-\theta}}$ where $T_i>0$ and $\theta>1$

Treat the distributions as independent across countries.

- T_i is country specific parameter governing the location of the distribution. (A bigger T_i implies that a high efficiency draw for any good j is more likely).

Think about T_i as country i's state of technology reflecting country i's absolute advantage across a continuum of goods.

$F_i(z) = e^{-T_i \cdot z^{-\theta}}$ where T_i>0 and **q**>1

- **q** parameter is common to all countries and reflects the amount of variation within distribution.
  (Bigger **q** implies less variability.)

  Think about q as a parameter regulating heterogeneity across goods in countries' relative efficiencies. It governs comparative advantage within a continuum of goods.

Resulting distribution of prices in different countries:

Country i presents country n with a distribution of prices:

$$G_{ni}(p) = \Pr[P_{ni} \leq p] = 1 - F_i(\frac{c_i \cdot d_{ni}}{p})$$

$$G_{ni}(p) = 1 - e^{-[T_i (c_i \cdot d_{ni})^{-\theta}] \cdot p^{\theta}}$$

How to get it:

Recall: $P_{ni} = \dfrac{c_i \cdot d_{ni}}{Z_i}$ and $F_i(z) = \Pr[Z_i \le z] = e^{-T_i \cdot z^{-\theta}}$.

Define:

$$G_{ni}(p) = \Pr[P_{ni} \le p]$$

$$G_{ni}(p) = \Pr[\frac{c_i \cdot d_{ni}}{Z_i} \le p] = 1 - \Pr[Z_i \le \frac{c_i \cdot d_{ni}}{p}]$$

$$= 1 - F[\frac{c_i \cdot d_{ni}}{p}]$$

$$= 1 - e^{-T_i \cdot \left(\frac{c_i \cdot d_{ni}}{p}\right)^{-\theta}} = 1 - e^{-T \cdot (c_i \cdot d_{ni})^{-\theta} \cdot p^{\theta}}$$

The lowest price for a good in country n (P_n) will be less than p unless each source's price is greater than p.

Therefore: the distribution $G_n(p) = \Pr[P_n \leq p]$ for what country n actually buys is:

$$G_n(p) = 1 - \prod_{i=1}^{N} [1 - G_{ni}(p)]$$

Inserting G_{ni} , price distribution inherits form of $G_{ni}(p)$:

$$G_n(p) = 1 - e^{-\phi_n \cdot p^{\theta}}$$

$$where\ \phi_n = \sum_{i=1}^{N} T_i (c_i \cdot d_{ni})^{-\theta}$$

The price parameter $\phi_n = \sum_{i=1}^{N} T_i (c_i \cdot d_{ni})^{-\theta}$ summarizes how:

1. states of technology around the world,
2. inputs costs around the world,
3. and geographic barriers

govern prices in each country n.

Special cases:

a) in zero-gravity world with no geographic barriers $d_{ni}=1$ for all n and i

   F is the same everywhere and the law of one price holds for each good

b) in autarky, with prohibitive geographic barriers
F$_n$ reduces to $T_n \cdot c_n^{-\theta}$

Country n's own state of technology downweighted by its input cost.

Price distribution has 3 important properties:

1. π_{ni} (the probability that country i provides a good at the lowest price in country n)

$$\pi_{ni} = \Pr[P_{ni}(j) \leq \min\{P_{ns}(j), s \neq i\}]$$

$$\pi_{ni} = \frac{T_i \cdot (c_i \cdot d_{ni})^{-\theta}}{\phi_n}$$

Continuum of goods implies, π_{ni} is also the fraction of goods that country n buys from country i.

2. Can be shown:

The price of a good that country n actually buys from **any** country i also has the distribution G_n.

$$\forall i \ \Pr[\mathrm{P_n} < p \mid P_n = P_{ni}] = G_n(p).$$

For goods that are purchased, conditioning on the source has no bearing on the good’s price.

The prices of goods actually sold in a country have the same distribution regardless of where they come from.

Corollary:

$$\boxed{\text{Country n's average expenditure per good does not vary by source.}}$$

Hence the fraction of goods that country n buys from country i, π_{ni} is also the fraction of its expenditure on goods from country i:

$$\pi_{ni} = \frac{X_{ni}}{X_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\phi_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\sum_{k=1}^{N} T_k (c_k d_{nk})^{-\theta}}$$

where X_n is country n's total spending and X_{ni} is spent (c.i.f.) on goods from i.

$$\frac{X_{ni}}{X_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\phi_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\sum_{k=1}^{N} T_k (c_k d_{nk})^{-\theta}}$$

Notice: this already resembles gravity equation.

Bilateral trade is related to the importer's total expenditure and to geographic barriers.

3. The exact price index for the CES function is:

$$p_n = \gamma \cdot \phi_n^{-1/\theta}$$

where $\gamma = \left[\Gamma \left(\frac{\theta + 1 - \sigma}{\theta} \right) \right]^{\frac{1}{1-\sigma}}$ and **G** is the Gamma function.

Connection between trade flows and price differences:

Divide $\frac{X_{ni}}{X_n}$ by $\frac{X_{ii}}{X_i}$ and substitute for **F** from price index p_n.

$$\frac{X_{ni}/X_n}{X_{ii}/X_i} = \frac{\phi_i}{\phi_n} d_{ni}^{-\theta} = \left(\frac{p_i d_{ni}}{p_n}\right)^{-\theta}$$

(Notice: p_i and p_n above are price indices for country i and n, not prices of some single good.)

Call the left hand side "country i's normalized import share in country n."

(Triangle inequality implies, it never exceeds one.)

$$\frac{X_{ni}/X_n}{X_{ii}/X_i} = \frac{\phi_i}{\phi_n} d_{ni}^{-\theta} = \left(\frac{p_i\, d_{ni}}{p_n}\right)^{-\theta}$$

- As overall prices in market n fall relative to prices in market i or as n becomes more isolated from i (higher d_{ni}) i’s normalized share in n declines.
- As the force of comparative advantage weakens (higher **q**), normalized import shares become more elastic w.r.t. the average relative price and to geographic barriers.
- A higher **q** means relative efficiencies are more similar across goods. There are fewer efficiency outliers that overcome differences in average prices or geographic barriers.

Empirical exploration of the trade-price relationship:

$$\frac{X_{ni}/X_{n}}{X_{ii}/X_{i}} = \frac{\phi_i}{\phi_n} d_{ni}^{-\theta} = \left(\frac{p_i d_{ni}}{p_n} \right)^{-\theta}$$

A)
Measure left-hand side by data on bilateral trade in manufactures among 19 OECD countries in 1990.
(normalized import shares never exceed 0.2)

Crude proxy for d_{ni} is distance.

Normalized import shares against distance between the corresponding country-pair (logarthmic scale).

Ignoring the price indices in $\frac{X_{ni}/X_n}{X_{ii}/X_i} = \frac{\phi_i}{\phi_n} d_{ni}^{-\theta} = \left(\frac{p_i d_{ni}}{p_n} \right)^{-\theta}$.

We will see the resistance that geography imposes on trade.

Inverse correlation.

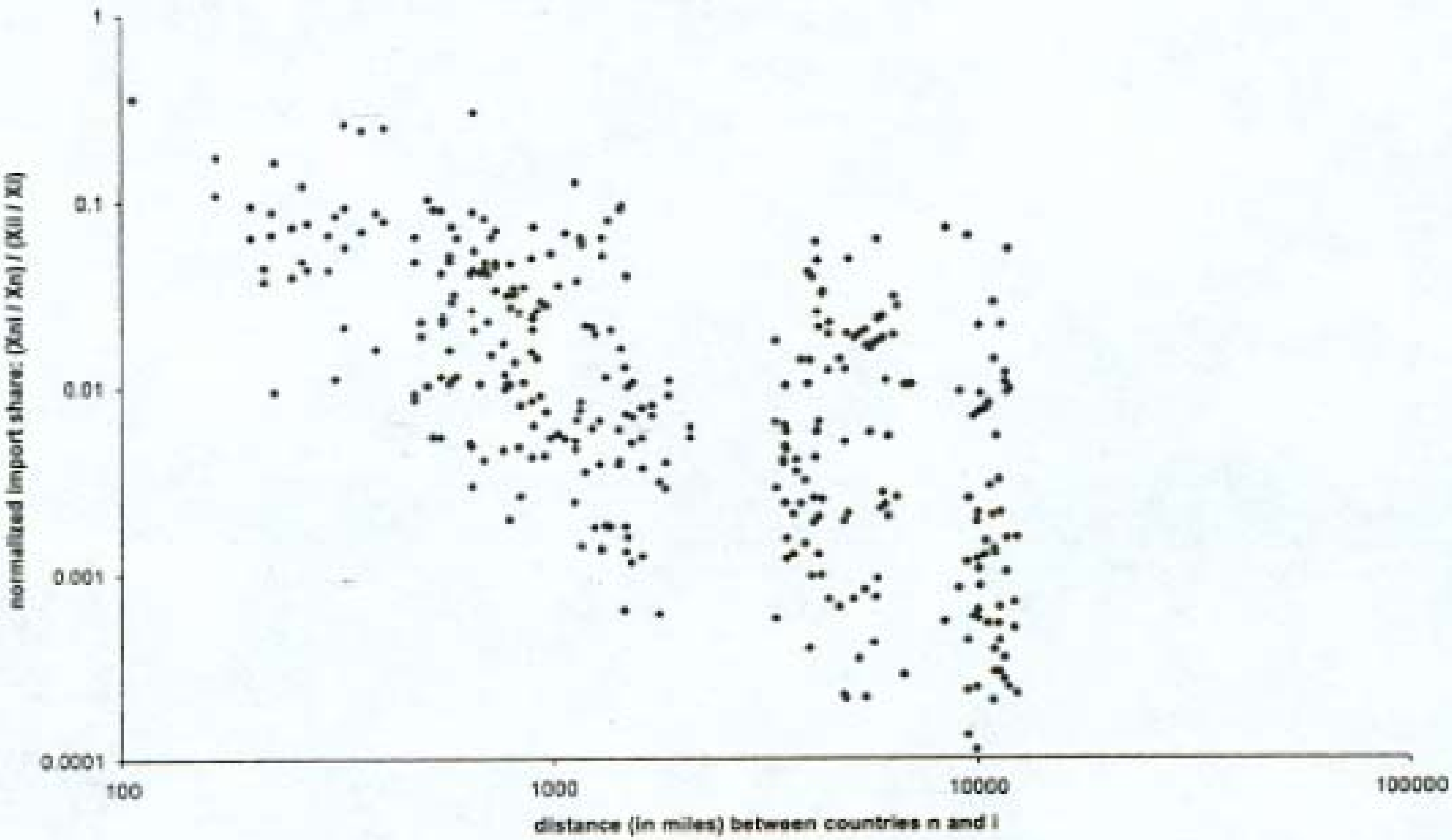


FIGURE 1.—Trade and geography.

$$\frac{X_{ni}/X_n}{X_{ii}/X_i} = \frac{\phi_i}{\phi_n} d_{ni}^{-\theta} = \left(\frac{p_i d_{ni}}{p_n} \right)^{-\theta}$$

B)

Retail prices in each of 19 OECD countries of 50 selected manufactured products were used to construct price measure.

Price measure: $\ln\left(\frac{p_i d_{ni}}{p_n} \right)$

Negative relationship between normalized import shares against price measure as model predicts.

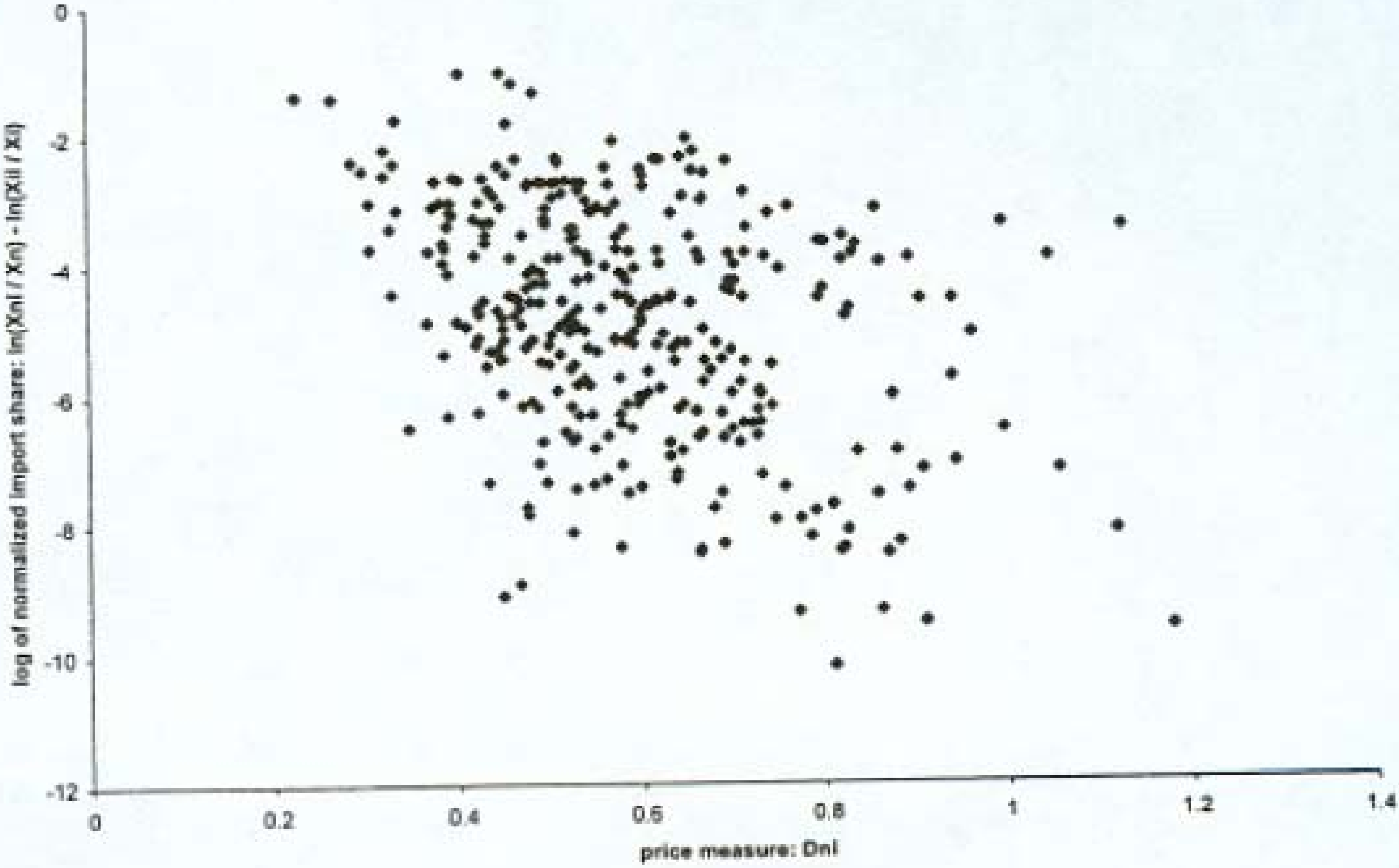


FIGURE 2.—Trade and prices.

Equilibrium input costs (so far input costs c_i were taken as given).

Strategy:

1. Decompose the input bundle into labor and intermediates.

2. Determinate prices of intermediates, given wages.

3. Determination of wages.

Production

- Production combines labor and intermediate input, with labor having a constant share **b**.
- Intermediates comprise the full set of goods combined according to the CES aggregator.
- The overall price index in country i, p_i, becomes appropriate index of intermediate goods prices there.
- The cost of an input bundle in country i:

$$c_i = w_i^{\beta} \cdot p_i^{1-\beta},$$

where w_i is the wage in country i.

Notice: $c_i(\mathbf{F}_i)$ through p_i and $\mathbf{F}_i(\sum_{i=1}^{N} T_i (c_i)^{-\theta})$.

Determination of price levels around the world:

Substituting $c_i = w_i^{\beta} \cdot p_i^{1-\beta}$ into $\phi_n = \sum_{i=1}^{N} T_i (c_i \cdot d_{ni})^{-\theta}$ and applying
$p_n = \gamma \cdot \phi_n^{-1/\theta}$,
we can get system of equations:

$$p_n = \gamma \cdot \left[\sum_{i=1}^{N} T_i (d_{ni} w_i^{\beta} p_i^{1-\beta})^{-\theta} \right]^{-1/\theta}$$

Numerical methods necessary.

Plug $c_i = w_i^{\beta} \cdot p_i^{1-\beta}$ into $\frac{X_{ni}}{X_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\phi_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\sum_{k=1}^{N} T_k (c_k d_{nk})^{-\theta}}$

to get expression for trade shares as functions of wages and parameters of the model:

$$\frac{X_{ni}}{X_n} = \pi_{ni} = T_i \left(\frac{\gamma d_{ni} w_i^{\beta} p_i^{1-\beta}}{p_n} \right)^{-\theta}$$

Labor market equilibrium

(They show how manufacturing fits into the larger economy.)

Denote: L_i manufacturing workers
X_n total spending on manufactures.

$$w_i L_i = \beta \sum_{n=1}^{N} \pi_{ni} X_n$$

Manufacturing labor income in country i is labor's share of country i's manufacturing exports around the world, including sales at home.

Denote Y_n aggregate final expenditures and **a** the fraction spent on manufactures.

Total manufacturing expenditures are:

$$X_n = \underbrace{\frac{1-\beta}{\beta} w_n L_n}_{\text{Demand for manufactures as intermediates by the manufacturing sector itself.}} + \underbrace{\alpha Y_n}_{\text{Final consumption of manufactures.}}$$

Aggregate final expenditures Y_n consist of value-added in manufacturing w_nL_n plus income generated in nonmanufacturing Y_n^O.

$$Y_n = w_n L_n + Y_n^O.$$

Assume nonmanufacturing output can be traded costlessly (not innocuous), and use it as numeraire.

To close the model simply, consider two polar cases:

1. Labor is mobile
(Workers can move freely between manufacturing and nonmanufacturing.)

Wage w_n given by productivity in nonmanufacturing and total income Y_n is exogenous.

Combining equations $w_i L_i = \beta \sum_{n=1}^{N} \pi_{ni} X_n$ and $X_n = \frac{1-\beta}{\beta} w_n L_n + \alpha Y_n$

get $$w_i L_i = \sum_{n=1}^{N} \pi_{ni} [(1-\beta) w_n L_n + \alpha \beta Y_n]$$

that determines manufacturing employment L_i.

2. Labor is immobile

- The number of manufacturing workers in each country is fixed at L_n.
- Nonmanufacturing income Y_n^O is exogenous.

Combining $w_i L_i = \beta \sum_{n=1}^{N} \pi_{ni} X_n$ and $X_n = \frac{1-\beta}{\beta} w_n L_n + \alpha Y_n$

we get:

$$w_i L_i = \sum_{n=1}^{N} \pi_{ni} [(1-\beta+\alpha\beta) w_n L_n + \alpha\beta Y_n^O]$$

which determines manufacturing wages w_i.

The full general equilibrium is comprised by:

$$p_n = \gamma \cdot \left[\sum_{i=1}^{N} T_i (d_{ni} w_i^{\beta} p_i^{1-\beta})^{-\theta} \right]^{-1/\theta}$$

$$\frac{X_{ni}}{X_n} = \pi_{ni} = T_i \left(\frac{\gamma d_{ni} w_i^{\beta} p_i^{1-\beta}}{p_n} \right)^{-\theta}$$

$$w_i L_i = \sum_{n=1}^{N} \pi_{ni} [(1-\beta) w_n L_n + \alpha \beta Y_n]$$

(Manufacturing employment for labor mobility.)

$$w_i L_i = \sum_{n=1}^{N} \pi_{ni} [(1-\beta+\alpha\beta) w_n L_n + \alpha \beta Y_n^O]$$

(Manufacturing wages for immobile case.)

Rich interaction among prices in different countries

makes analytic solution unattainable.

Estimates

Estimates with source effects
(characteristics of trading partners and distance between them).

$$\frac{X_{ni}}{X_n} = \pi_{ni} = T_i \left(\frac{\gamma d_{ni} w_i^{\beta} p_i^{1-\beta}}{p_n} \right)^{-\theta}$$

From estimating it, we can learn about states of technology and geographic barriers.

Normalize by the importer's home sales (divide by X_{nn}/X_n)

$$\frac{X_{ni}}{X_{nn}} = \frac{T_i}{T_n} \left(\frac{w_i}{w_n} \right)^{-\theta\beta} \left(\frac{p_i}{p_n} \right)^{-\theta(1-\beta)} d_{ni}^{-\theta}$$

After a few other rearranging steps, finally get equation to estimate:

$$\ln\left(\frac{X'_{ni}}{X'_{nn}}\right) = -\theta \cdot \ln d_{ni} + \frac{1}{\beta}\ln\frac{T_i}{T_n} - \theta \ln\frac{w_i}{w_n}$$

where:

$$\ln X'_{ni} \equiv \ln X_{ni} - \frac{1-\beta}{\beta}\ln\left(\frac{X_i}{X_{ii}}\right).$$

Defining $S_i \equiv \frac{1}{\beta}\ln T_i - \theta \cdot \ln w_i$

Think of S_i as a measure of country i's competitiveness, its state of technology adjusted for its labor costs.

$$\ln\left(\frac{X'_{ni}}{X'_{nn}}\right) = -\theta \cdot \ln d_{ni} + S_i - S_n$$

Left-hand side is calculated:

- The same data on bilateral trade of 19 OECD countries.
  (How many observations? 19*19-19=361-19=342.
- Set **b**=0.21 (the average labor share in gross manufacturing production in the sample).
- X_n includes imports from all countries in the world since price of intermediates reflect imports from all sources.

$$\ln\left(\frac{X'_{ni}}{X'_{nn}}\right) = -\theta \cdot \ln d_{ni} + S_i - S_n$$

Right-hand side is calculated:

- S_i captured as the coefficients on source-country dummies.
- Proxies for d_{ni} (reflecting proximity, language and treaties).

For all $n \neq i$ we have:

$$\ln d_{ni} = d_k + b + l + e_h + m_n + \delta_{ni}$$

$$\ln d_{ni} = d_k + b + l + e_h + m_n + \delta_{ni}$$

where dummies are:

- d_k (k=1, ….6) is the effect of distance between n and i lying in the k^{th} interval,
- b is the effect of n and i sharing a border,
- l is the effect of n and i sharing a language,
- e_h (h=1,2) is the effect of n and i both belonging to trading area h (EFTA and EC),
- m_n (n==1, …19) is an overall destination effect,
- δ_{ni} is error term capturing geographic barriers arising from all other factors.

- Error term δ_{ni} is decomposed to capture potential reciprocity in geographic barriers:

$$\delta_{ni} = \delta_{ni}^2 + \delta_{ni}^1$$

δ_{ni}^2 the country-pair specific component affects two-way trade, such that $\delta_{ni}^2 = \delta_{in}^2$,

δ_{ni}^1 affects one-way trade.

GLS estimation of:

$$\ln\left(\frac{X'_{ni}}{X'_{nn}}\right) = S_i - S_n - \theta m_n - \theta d_k - \theta b - \theta l - \theta e_h + \delta_{ni}^2 + \delta_{ni}^1$$

- Results: estimates of S_i indicate Japan is the most competitive country in 1990, Belgium and Greece the least competitive.
- Distance inhibits trade a lot.
- The EC and EFTA do not play a major role.

TABLE III

BILATERAL TRADE EQUATION

Variable		est.	s.e.
Distance [0, 375)	$-\theta d_1$	−3.10	(0.16)
Distance [375, 750)	$-\theta d_2$	−3.66	(0.11)
Distance [750, 1500)	$-\theta d_3$	−4.03	(0.10)
Distance [1500, 3000)	$-\theta d_4$	−4.22	(0.16)
Distance [3000, 6000)	$-\theta d_5$	−6.06	(0.09)
Distance [6000, maximum]	$-\theta d_6$	−6.56	(0.10)
Shared border	$-\theta b$	0.30	(0.14)
Shared language	$-\theta l$	0.51	(0.15)
European Community	$-\theta e_1$	0.04	(0.13)
EFTA	$-\theta e_2$	0.54	(0.19)

Country	Source Country			Destination Country		
		est.	s.e.		est.	s.e.
Australia	S_1	0.19	(0.15)	$-\theta m_1$	0.24	(0.27)
Austria	S_2	−1.16	(0.12)	$-\theta m_2$	−1.68	(0.21)
Belgium	S_3	−3.34	(0.11)	$-\theta m_3$	1.12	(0.19)
Canada	S_4	0.41	(0.14)	$-\theta m_4$	0.69	(0.25)
Denmark	S_5	−1.75	(0.12)	$-\theta m_5$	−0.51	(0.19)
Finland	S_6	−0.52	(0.12)	$-\theta m_6$	−1.33	(0.22)
France	S_7	1.28	(0.11)	$-\theta m_7$	0.22	(0.19)
Germany	S_8	2.35	(0.12)	$-\theta m_8$	1.00	(0.19)
Greece	S_9	−2.81	(0.12)	$-\theta m_9$	−2.36	(0.20)
Italy	S_{10}	1.78	(0.11)	$-\theta m_{10}$	0.07	(0.19)
Japan	S_{11}	4.20	(0.13)	$-\theta m_{11}$	1.59	(0.22)
Netherlands	S_{12}	−2.19	(0.11)	$-\theta m_{12}$	1.00	(0.19)
New Zealand	S_{13}	−1.20	(0.15)	$-\theta m_{13}$	0.07	(0.27)
Norway	S_{14}	−1.35	(0.12)	$-\theta m_{14}$	−1.00	(0.21)
Portugal	S_{15}	−1.57	(0.12)	$-\theta m_{15}$	−1.21	(0.21)
Spain	S_{16}	0.30	(0.12)	$-\theta m_{16}$	−1.16	(0.19)
Sweden	S_{17}	0.01	(0.12)	$-\theta m_{17}$	−0.02	(0.22)
United Kingdom	S_{18}	1.37	(0.12)	$-\theta m_{18}$	0.81	(0.19)
United States	S_{19}	3.98	(0.14)	$-\theta m_{19}$	2.46	(0.25)

Total Sum of squares	2937	Error Variance:	
Sum of squared residuals	71	Two-way ($\theta^2\sigma_2^2$)	0.05
Number of observations	342	One-way ($\theta^2\sigma_1^2$)	0.16

Notes: Estimated by generalized least squares using 1990 data. The specification is given in equation (30) of the paper. The parameter are normalized so that $\sum_{i=1}^{19} S_i = 0$ and $\sum_{n=1}^{19} m_n = 0$. Standard errors are in parentheses.

Counterfactuals:

Highly stylized model (suppressed heterogeneity in geographic barriers across manufacturing goods)

- The Gains From Trade
- The Benefits of Foreign Technology
- Eliminating Tariffs
- Trade diversion in the EC
- US Unilateral Tariff Elimination
  If US remove tariffs on its own, everyone benefits except the USA. Biggest winner is Canada if labor is mobile.
- General Multilateral Tariff Elimination

- Technology vs. Geography

  For smaller countries manufacturing shrinks as geographic barriers diminish from their autarky level. Production shifts to larger countries where inputs are cheaper. As geographic barriers continue to fall, however, the forces of technology take over and the fraction of the labor force in manufacturing grows, often exceeding its autarky level.

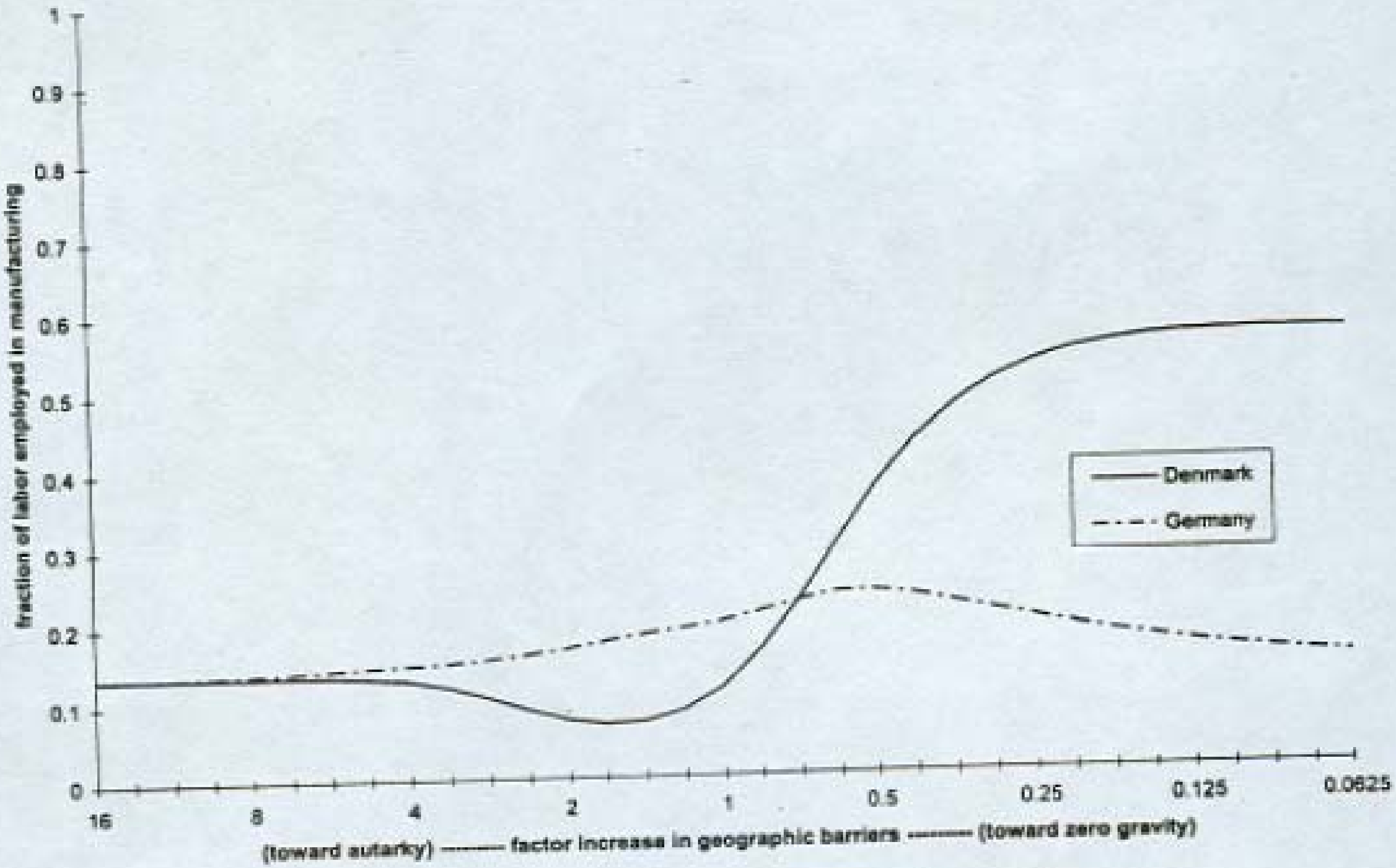


FIGURE 3.—Specialization, technology, and geography.

Conclusion

- Ricardian model capturing the importance of geographic barriers in curtailing trade flows.
- The model delivers equations relating bilateral trade around the world to parameters of technology and geography.