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Economics 507a: International Trade
Lecture 6
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Eaton and Kortum ‘s Ricardian Extravaganza

EK develop an elaborate Ricardian model with multiple countries, intermediate inputs, and particular distributions for the country-specific productivity levels, good by good. Then they fit their model to data on country characteristics to try to determine the importance of productivity differences in driving trade, as well as transport costs and other factors.

The model focuses on the manufacturing sector, where products are differentiated, but embeds this sector in a very cursory general equilibrium model. We’ll limit our discussion to manufacturing.

Assumptions:

- $Z_i(j) =$ amount of good *j* that a bundle of inputs can produce in country *i* (exogenous)
- $P[Z_i(j) \le z] = e^{-T_i z^{-\theta}}$ Frechet, or “Type II extreme value” distribution, both T_i and θ are exogenous to the model. That is, looking across goods in country *i*, efficiency follows a Frechet distribution. Countries with big *T* values are more efficient.
- c_i = cost of a unit bundle of inputs, made up of labor and materials (dependent on wages and prices)
- $1/d_{ni} =$ fraction of exports from *i* to *n* that arrives at *n* (exogenous to the model)
- $P_{ni}(j) = c_i d_{ni} / Z_i(j)$ = price country *n* faces for good *j* when buying from country *i*
- $P_n(j) = \min\{P_{nj}(j); i = 1, \ldots, N\}$ = the price of good *j* observed in country *n*.
- or $\dfrac{Z_i(j)}{c_i d_{ni}} = \max\left\{\dfrac{Z_s(j)}{c_s d_{ns}}; s = 1, \cdots, N\right\}$.
- Each good is used for final consumption and as an intermediate input. Each country uses the lowest cost source for each good it consumes, inclusive of transport costs.

- All consumers and users of intermediate inputs value goods according to the same CES function: $U = \left[\int_0^1 Q(j)^{\sigma-1/\sigma} dj \right]^{\sigma/\sigma-1}$

<u>Implication 1</u>
The price that country *i* offers to country *n* for good *j* has cumulative distribution $P[P_{ni}(j) \le p] \equiv G_{ni}(p) = 1 - \exp\left[-\phi_i d_{ni}{}^{-\theta} p^{\theta}\right]$ where $\phi_i = T_i c_i{}^{-\theta}$.

<u>Proof</u>

$$P[P_{ni}(j) \le p] \equiv G_{ni}(p) = P\left[p \ge \frac{c_i d_{ni}}{Z_i} \right] = P\left[Z_i \ge \frac{c_i d_{ni}}{p} \right]$$
$$= 1 - P\left[Z_i \le \frac{c_i d_{ni}}{p} \right] = 1 - \exp\left[-T_i \left(\frac{c_i d_{ni}}{p} \right)^{-\theta} \right] = 1 - \exp\left[-\phi_i d_{ni}{}^{-\theta} p^{\theta}\right] \qquad (2)$$

<u>Implication 2</u>
The distribution of *observed* prices for any good *j* in country *n* is $G_n(p) = 1 - \exp\left(-\Phi_n p^{\theta}\right)$, where $\Phi_n \equiv \sum_{i=1}^{N} \phi_i d_{ni}^{-\theta} = \sum_{i=1}^{N} T_i \left(c_i d_{ni}\right)^{-\theta}$.

<u>Proof</u>

$$P[P_n(j) \le p] = G_n(p) = 1 - \prod_{i=1}^{N} \left(1 - G_{ni}(p)\right) = 1 - \exp\left(-\Phi_n p^{\theta}\right) \qquad (3)$$

Note that the max of a set of Frechet-distributed random variables is itself Frechet-distributed. Also note that increases in *N* reduce prices, given input costs—this is the fundamental source of gains from trade. Higher efficiencies and lower transport costs also lead to lower prices.

<u>Implication 3</u>

The probability that country *n* buys good *j* from country *i* is $\pi_{ni} = \frac{d_{ni}{}^{-\theta} \phi_i}{\Phi_n}$:

<u>Proof</u>

$$\pi_{ni} = \int_0^{\infty} \left[\prod_{s \ne i} \left(1 - G_{ns}(p)\right) \right] dG_{ni}(p) = \int_0^{\infty} \left[\prod_{s \ne i} \left(1 - G_{ns}(p)\right) \right] \left[e^{-d_{ni}{}^{-\theta} p^{\theta} \phi_i} \left(\theta d_{ni}{}^{-\theta} p^{\theta-1} \phi_i \right) \right] dp \qquad (4)$$
$$= \int_0^{\infty} \left[\prod_{s \ne i} \left(1 - G_{ns}(p)\right) \right] \left[1 - G_{ni}(p)\right] \left(\theta d_{ni}{}^{-\theta} p^{\theta-1} \phi_i \right) dp = \int_0^{\infty} \left[\prod_{s=1,N} \left(1 - G_{ns}(p)\right) \right] \left(\theta d_{ni}{}^{-\theta} p^{\theta-1} \phi_i \right) dp$$

$$= \int_0^\infty (1 - G_n(p))\left(\theta \, d_{ni}^{-\theta} p^{\theta-1} \phi_i\right) dp$$

aside: $d(1 - G_n(p)) = (1 - G_n(p)) \cdot \left(-\theta \Phi_n p^{\theta-1}\right) dp$

$$= \int_0^\infty d(1 - G_n(p)) \left(\frac{-d_{ni}^{-\theta} \phi_i}{\Phi_n} \right) = \left(\frac{-d_{ni}^{-\theta} \phi_i}{\Phi_n} \right) (1 - G_n(p)) \Big|_0^\infty = \frac{d_{ni}^{-\theta} \phi_i}{\Phi_n}$$

Implication 4
The price of any good *j* that country *n* buys also has the distribution $G_n(p)$, and is *not* dependent upon source.

Proof
The probability of a purchase from country *i* at price no greater than *p* is same as in (4), but integrate to *p* instead of infinity:

$$\int_0^p \left[\prod_{s \neq i} (1 - G_{ns}(q)) \right] dG_{ni}(q) =$$

$$= \left(\frac{-d_{ni}^{-\theta} \phi_i}{\Phi_n} \right) (1 - G_n(q)) \Big|_0^p = \frac{d_{ni}^{-\theta} \phi_i}{\Phi_n} [(1 - G_n(p)) - 1] = \pi_{ni} G_n(p) \qquad (5)$$

Further, $P[P_n(j) \leq p \mid source\ i] = P[source\ i \cap P_n(j) \leq p] / P[source\ i] = \pi_{ni} G_n(p) / \pi_{ni}$. So the unconditional (and conditional) probability that any good *j* will be purchased by *n* at a price no greater than *p* are both $G_n(p)$. Highly competitive countries are relatively likely to be the low cost source, but the distribution of the prices they offer when they win a market is no different from the prices other countries offer when *they* win a market.

Implication 5
The exact price index for consumers and intermediate goods users is

$$p_n = \gamma \Phi_n^{-1/\theta} \qquad (6)$$

Proof

To see this, note that the CES utility function $U = \left[\int_0^1 Q(j)^{\sigma-1/\sigma} dj \right]^{\sigma/\sigma-1}$ implies that, given income level *Y*, consumers demand $Q(j) = \left(\frac{P_j^{-\sigma}}{\int_0^1 P_s^{1-\sigma} ds} \right) Y$ units of good *j*. Substituting these demands into the utility functions yields the indirect utility function:

$$U = \left[\int_0^1 \left(\frac{Y \cdot P_j^{-\sigma}}{\int_0^1 P_s^{1-\sigma} ds} \right)^{\sigma-1/\sigma} dj \right]^{\sigma/\sigma-1} = \frac{Y}{\int_0^1 P_s^{1-\sigma} ds} \left[\int_0^1 \left(P_j^{1-\sigma} \right) dj \right]^{\sigma/\sigma-1} = Y \left[\int_0^1 \left(P_j^{1-\sigma} \right) dj \right]^{1/\sigma-1} \quad (7)$$

Given that each of the P_j has the cumulative distribution $G_n(p)$, the expectation of $P_j^{1-\sigma}$ is $E\left(P_j^{1-\sigma}\right) = \Gamma\left(1 - \frac{\sigma-1}{\theta}\right) \Phi_n^{(\sigma-1)/\theta}$, where Γ is the Gamma function associated with the Gamma distribution. (Eaton and Kortum show this by noting that the moment generating function for $x = -\ln p$ is $E\left[e^{tx}\right] = \Phi_n^{t/\theta} \Gamma(1 - t/\theta)$, then evaluating this function at $t = \sigma - 1$.)

Taking the expected price in each market and plugging it into the indirect utility function therefore yields:

$$E[U] = Y \left[\Gamma(\sigma, \theta) \Phi_n^{\frac{\sigma-1}{\theta}} \right]^{1/\sigma-1} = Y\gamma^{-1} \Phi_n^{1/\theta}, \quad (8)$$

where the constant γ depends on θ and σ in a messy way that won't matter. (There is a Jensen's inequality issue here that Eaton and Kortum seem to be ignoring.) Clearly, $\Phi_n^{-1/\theta}$ is an exact price deflator because expected utility is homogeneous of degree zero in this index and *Y*. (Note that $\Phi_n^{-1/\theta} = \left[\sum_{i=1}^{N} T_i \left(c_i d_{ni} \right)^{-\theta} \right]^{\frac{-1}{\theta}}$ is a CES function itself.)

<u>Closing the model</u>

The model can be closed by expressing prices as functions of wages and pinning down wages with a homogeneous product sector that produces traded goods. First, assume Cobb-Douglas production functions in labor and intermediates, so the unit cost function is: $c_i = w_i^{\beta} p_i^{1-\beta}$ in all sectors and countries. Substituting this into $\Phi_n \equiv \sum_{i=1}^{N} \phi_i d_{ni}^{-\theta} = \sum_{i=1}^{N} T_i \left(c_i d_{ni} \right)^{-\theta}$, and the result into $p_n = \gamma \Phi_n^{-1/\theta}$ yields *N* equations in *N* prices and *N* wages. The former can be found in terms of the latter. Then pin down wages by letting the homogeneous good be a costlessly traded numeraire, so that each country's wage reflects its productivity in terms of that good: $\frac{w_i^{\beta} p_i^{1-\beta}}{Z_{0i}} = 1$. This gives *N* more equations in *N* wages. (The share of labor in manufacturing adjusts in each country so that trade flows balance.)

Empirical implications

We're now ready to say something empirical about how technology differences and transport costs shape trade in manufactured products and thereby influence welfare. From this point onward we'll be talking about trade shares at the level of manufacturing industry, aggregating over the individual goods.

Since the prices that country *n* pays do not depend upon the source of its goods (only Φ_n and θ), the share of a particular country, *i*, in *n*'s expenditures is the same as its share in the number of goods:

$$\frac{X_{ni}}{X_n} = \pi_{ni} = \frac{T_i (c_i d_{ni})^{-\theta}}{\Phi_n} = \frac{T_i (c_i d_{ni})^{-\theta}}{\sum_{k=1,N} T_k (c_k d_{nk})^{-\theta}} \qquad (9)$$

where X_{ni} is country *n*'s spending on country *i*'s goods and X_n is *n*'s total spending.

Aside: Relation to gravity equations

The EK model provides a new explanation for why gravity equations work. A simple gravity equation expresses the bilateral trade between two countries as a function of their size (GDP) and the distance between them. Defining the exporting country's total sales as $Q_i = \sum_{m=1}^{N} X_{mi} = T_i c_i^{-\theta} \sum_{m=1}^{N} \frac{d_{mi}^{-\theta} X_m}{\Phi_m}$, one can solve for $T_i c_i^{-\theta} = Q_i \Big/ \sum_{m=1}^{N} \frac{d_{mi}^{-\theta} X_m}{\Phi_m}$. From (6), $p_n = \gamma \Phi_n^{-1/\theta}$ implies $\Phi_n = p_n^{-\theta} \gamma^{1/\theta}$, so we can re-state the share equation above this box to obtain:

$$X_{ni} = \frac{X_n \left(\frac{d_{ni}}{p_n} \right)^{-\theta}}{\sum_{k=1,N} X_m \left(\frac{d_{mi}}{p_m} \right)^{-\theta}} Q_i \qquad (10)$$

That is, imports of *n* from *i* depend upon the size of *n*, the size of *i* and the distance between the two countries. The latter is adjusted for cost differences.

note: This is not the only way to motivate gravity equations. We'll see that monopolistic competition models can be used to do the same.

Intra-country technology dispersion

By exploiting the structure of the EK model, we can back out information on country-specific efficiency and distance barriers from bilateral trade flows.

First, note that θ can be estimated using data on bilateral trade flows along with information on prices and distance.

- Price data come from international comparisons of prices for the same bundle of 50 manufactured goods. The average ratio across commodities measures relative commodity prices: $\log\left(\frac{p_i}{p_n}\right) = \frac{1}{J}\sum_{j=1,J}\log\left(\frac{p_i(j)}{p_n(j)}\right)$.

- Distance really means physical plus other barriers to trade (language, terrain, commercial policy, etc.) Since $p_n(j) \le p_i(j)d_{ni}$ with equality when the good is purchased from *i*, distance can be imputed as the highest value of $p_n(j)/p_i(j)$ across commodities. (More precisely, EK use the second highest value to reduce sensitivity to outliers.)

Substituting $c_i = w_i^{\beta} p_i^{1-\beta}$ into the expenditure share equation above and using $p_n = \gamma\Phi_n^{-1/\theta}$ yields:

$$\frac{X_{ni}}{X_n} = \pi_{ni} = \frac{T_i(w_i^{\beta}p_i^{1-\beta}d_{ni})^{-\theta}}{\Phi_n} = T_i\left(\frac{w_i^{\beta}p_i^{1-\beta}\gamma d_{ni}}{p_n}\right)^{-\theta} \tag{11}$$

Forming the ratio $\frac{X_{ni}/X_n}{X_{ii}/X_i} = \frac{\Phi_i}{\Phi_n}d_{ni}^{-\theta} = \left(\frac{p_i\,d_{ni}}{p_n}\right)^{-\theta}$, where the last equality follows from $\Phi_n = p_n^{-\theta}\gamma^{1/\theta}$. The bigger is θ, recall, the less dispersion in productivity draws and thus the more similar countries are. This is why market shares become more responsive to factor price differences as θ goes up.

Figure 2 present the scatter plot for $\log\left(X_{ni}/X_n\right) - \log\left(X_{ii}/X_i\right), \log\left(\frac{p_i\,d_{ni}}{p_n}\right)$. Since theory says the line should pass through the origin, a simple ratio of means provides a consistent estimator that is robust to (country-specific) measurement error. The implied $\hat{\theta} = 8.28$.

<u>The roles of distance and inter-country technology dispersion</u>

Next, EK use this $\hat{\theta}$ to estimate other model parameters and impute the role technology differences and distance differences in driving trade flows.

First use (11) to form the ratio of the expenditure share for good from *i* versus (home) goods from *n*:

$$\frac{X_{ni}}{X_{nn}} = \frac{T_i}{T_n}\left(\frac{w_i^{\beta} p_i^{1-\beta} d_{ni}}{w_n^{\beta} p_n^{1-\beta}}\right)^{-\theta} = \frac{T_i}{T_n} d_{ni}^{-\theta}\left(\frac{w_i}{w_n}\right)^{-\theta\beta}\left(\frac{p_i}{p_n}\right)^{-\theta(1-\beta)} \qquad (12)$$

Next get prices out of the picture because they're endogenous and also hard to measure. Solve for relative prices by evaluating the share equation for home sales in both country *i* and country *j*:

$$\frac{X_{nn}}{X_n} = T_n\left(\frac{w_n^{\beta} p_n^{1-\beta}\gamma}{p_n}\right)^{-\theta} = p_n^{-\theta\beta} T_n w_n^{-\theta\beta}, \qquad \frac{X_{ii}/X_i}{X_{nn}/X_n} = \frac{T_i}{T_n}\frac{p_i^{\theta\beta} w_i^{-\theta\beta}}{p_n^{\theta\beta} w_n^{-\theta\beta}}$$

$$\frac{p_i}{p_n} = \left(\frac{w_i}{w_n}\right)\left(\frac{X_{ii}/X_i}{X_{nn}/X_n}\right)^{-1/\theta\beta}\left(\frac{T_i}{T_n}\right)^{-1/\theta\beta} \qquad (13)$$

Using this expression to eliminate prices from the share equation, we obtain

$$\frac{X_{ni}}{X_{nn}} = \left(\frac{T_i}{T_n}\right)^{1/\beta} d_{ni}^{-\theta}\left(\frac{w_i}{w_n}\right)^{-\theta}\left(\frac{X_{ii}/X_i}{X_{nn}/X_n}\right)^{(1-\beta)/\beta} \qquad (14)$$

Finally, we can bring shares over to the left-hand side by defining $\ln X'_{ni} = \ln X_{ni} - \left[\frac{1-\beta}{\beta}\right]\ln\left(\frac{X_i}{X_{ii}}\right)$, so that $\ln\left(\frac{X'_{ni}}{X'_{ni}}\right) = -\theta \ln d_{ni} + S_i - S_n$ where $S_i \equiv \frac{1}{\beta}\ln T_i - \theta \ln w_i$ is a measure of the competitiveness of country *i*. By fixing β at the average labor share in manufacturing income (0.21) and parameterizing d_{ni} as a function of distance (*d*), effect of sharing a border (*b*), effect of sharing a language (ℓ), effect of belonging to the same trading area (*e*) and an "overall destination effect" (*m*), the model to be estimated emerges:

$$\ln\left(\frac{X'_{ni}}{X'_{nn}}\right) = S_i - S_n - \theta m_n - \theta d_k - \theta b - \theta\ell - \theta e_h + \theta\delta_{ni}^2 + \theta\delta_{ni}^1 \qquad (15)$$

where δ_{ni}^2 is the error component that affects two-way trade (barriers common to both countries—a mountain between them), while δ_{ni}^1 affects one-way trade (e.g., tariffs in one of the countries). This error specification leads to GLS estimation. The data are bilateral trade flows for 19 countries (342 observations).

Note: The overall destination effect m_n is identified by the observations for country *n*'s imports, while S_n is identified by observations on country *n*'s exports.

Results are presented in Table 3.

Japan is the most competitive country, followed by the U.S. At the other extreme, Belgium and Greece are the least competitive.

Increased distance substantially reduces trade, while shared language increases. The other variables are not very important. Dividing by θ gives the correct percentage effects, as we will see shortly.

Table 5 disaggregates the country competitiveness effect into technical efficiency and factor price components. The research stock matters, as does the wage rate. Human capital doesn't seem very important. (Missing: physical capital—including it would mean admitting that it belonged in the model somehow.)

Table 7 calculates the effects of the various types of distance and efficiency on trade.

Finally, by solving the model subject to autarky restrictions, it is possible to determine the implied gains from trade (table 8). Similarly, setting all d_{ni} =1, it is possible to calculate the implied gains that would result if all distance barriers were eliminated (table 9). The former is fairly modest, especially for large countries. This is consistent with other CGE studies. On the other hand, the potential gains from wholesale elimination of trade frictions are quite large!