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1 Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?

Alan V. Deardorff

1.1 Introduction

It has long been recognized that bilateral trade patterns are well described empirically by the so-called gravity equation, which relates trade between two countries positively to both of their incomes and negatively to the distance between them, usually with a functional form that is reminiscent of the law of gravity in physics. It also used to be frequently stated that the gravity equation was without theoretical foundation. In particular, it was claimed that the Heckscher-Ohlin (HO) model of international trade was incapable of providing such a foundation, and perhaps even that the HO model was theoretically inconsistent with the gravity equation. In this paper I will take another look at these issues. It is certainly no longer true that the gravity equation is without a theoretical basis, since several of the same authors who noted its absence went on to provide one. I will briefly review their contributions in a moment. Since none of them build directly on an HO base, it might be supposed that the empirical success of the gravity equation is evidence against the HO model, as at least one researcher has implied by using the gravity equation as a test of an alternative model incorporating monopolistic competition. I will argue, however, that the HO model, at least in some of the equilibria that it permits, admits easily of interpretations that accord readily with the gravity equation. At the same time, developing these interpretations can yield additional insights about why bilateral trade patterns in some cases depart from the gravity equation as well.

There are two keys to these results, which once stated may make the rest of

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the paper obvious to those well-schooled in trade theory. The two keys open doors to two different cases of HO-model equilibria, one with frictionless trade and one without.

With frictionless trade—that is, literally zero barriers to trade of all sorts, including both tariffs and transport costs—the key is that trade is just as cheap, and therefore no less likely, as domestic transactions. Therefore, instead of thinking as we normally do of countries first satisfying demands out of domestic supply and then importing only what is left, we should think of demanders as being indifferent among all equally priced sources of supply, both domestic and foreign. Suppliers likewise should not care about to whom they sell. The HO model (and other models based solely on comparative advantage and perfect competition) is usually examined only for its implications for net trade, and we then jump to the conclusion that gross trade flows are equal to net. But with no trade impediments, there is no reason for trade to be this small. If instead we allow markets to be settled randomly among all possibilities among which producers and consumers are indifferent, then trade flows will generally be larger and will fall naturally into a gravity-equation configuration, in a frictionless form without a role for distance. With identical preferences across countries, this configuration is particularly simple. With nonidentical preferences it is a bit more complex, but it is also more instructive.

The other key is to the case of trade in the presence of trade impediments. If there exist positive impediments to all trade flows, however small, then the HO model cannot have factor price equalization (FPE) between any two countries that trade with each other. For if they did have FPE, then their prices of all goods would be identical and neither could overcome the positive barrier on its exports to the other. Since we do observe trade between every pair of countries that we care about, it follows that the HO equilibria we look at with impeded trade should be ones without FPE between any pair of countries. If we assume also that the number of goods in the world is extremely large compared to the number of factors, it will be true that for almost all goods only one country will be the least-cost producer. With trade barriers this does not imply complete specialization by countries in largely different goods, but it makes such a case more plausible than might have been thought otherwise. In any case, motivated by this observation, I will study bilateral impeded trade under the assumption that each good is produced by only one country. With that assumption, bilateral trade patterns in the HO model are essentially the same as in other models with differentiated products, and it is no surprise that the gravity equation emerges once again. My contribution here will be to derive bilateral trade in terms of incomes and trade barriers in a form that may be more readily interpretable than before.

None of this should be very surprising, although I admit that this is much clearer to me now than it was when I started thinking about it. All that the gravity equation says, after all, aside from its particular functional form, is that bilateral trade should be positively related to the two countries' incomes and negatively related to the distance between them. Transport costs would surely yield the latter in just about any sensible model. And the dependence on incomes would also be hard to avoid. The size of a country obviously puts an upper limit on the amount that it can trade (unless it simply reexports, which one normally excludes), so that small countries necessarily trade little. For income not to be positively related to trade, it would therefore have to be true also that large countries trade very little, at least on average. Therefore, the smaller the smallest countries are, the less must all countries trade in order to avoid getting a positive relationship between size and trade. Looked at in that way, it would therefore be very surprising if some positive relationship between bilateral trade and national incomes did not also emerge from just about any sensible trade model. The HO model has some quirky features, but in this respect, at least, it turns out to be sensible.

As for the functional form, a simple version of the gravity equation—what I will call the standard gravity equation—is typically specified as

$$T_{ij} = A\frac{Y_i Y_j}{D_{ij}} \tag{1}$$

where T_{ij} is the value of exports from country i to country j, the Ys are their respective national incomes, D_{ij} is a measure of the distance between them,[1] and A is a constant of proportionality. While this particular multiplicative functional form may not be obvious, the easiest alternative of a linear equation clearly would not do, for trade between two countries must surely go to zero as the size of either goes to zero. None of this constitutes a derivation of the gravity equation, of course, but it does suggest why one would expect something like it to hold in any plausible model.

I turn in section 1.2 to a brief review of the literature, followed by the two cases just mentioned: frictionless trade in section 1.3 and impeded trade in section 1.4.

1.2 Theoretical Foundations for the Gravity Equation

As has been noted many times, the gravity equation for describing trade flows first appeared in the empirical literature without much serious attempt to justify it theoretically. Tinbergen (1962) and Pöyhönen (1963) did the first econometric studies of trade flows based on the gravity equation, for which they gave only intuitive justification. Linnemann (1966) added more variables and went further toward a theoretical justification in terms of a Walrasian general equilibrium system, but the Walrasian model tends to include too many

1. Clearly this measure should not go to zero for adjacent countries, or equation (1) would yield infinite trade between them. Empirical work typically uses distance between national capitals. For theoretical purposes below, it is convenient to use a measure that starts at one (such as one plus distance) to accommodate transactions of a country with itself.

explanatory variables for each trade flow to be easily reduced to the gravity equation. Leamer and Stern (1970) followed Savage and Deutsch (1960) in deriving it from a probability model of transactions. Their approach was very similar to what I will suggest below, but they applied it only to trade, not to all transactions, and they did not make any explicit connection with the HO model. Leamer (1974) used both the gravity equation and the HO model to motivate explanatory variables in a regression analysis of trade flows, but he did not integrate the two approaches theoretically.

These contributions were followed by several more formal attempts to derive the gravity equation from models that assumed product differentiation. Anderson (1979) was the first to do so, first assuming Cobb-Douglas preferences and then, in an appendix, constant-elasticity-of-substitution (CES) preferences. In both cases he made what today would be called the Armington assumption, that products were differentiated by country of origin. His framework was in fact very similar to what I will examine here with impeded trade, although I motivate the differentiation among products, as already noted, by the HO model's case of non-FPE and specialization rather than by the Armington assumption. Anderson modeled preferences over only traded goods, while I will assume for simplicity that they hold over all goods. Anderson's primary concern was to examine the econometric properties of the resulting equations, rather than to extract easily interpretable theoretical implications as I seek here.

Finally, Jeffrey Bergstrand has explored the theoretical determination of bilateral trade in a series of papers. In Bergstrand (1985) he, like Anderson, used CES preferences over Armington-differentiated goods to derive a reduced-form equation for bilateral trade involving price indexes. Using GDP deflators to approximate these price indexes, he estimated his system in order to test his assumptions of product differentiation. For richness his CES preferences were also nested, with a different elasticity of substitution among imports than between imports and domestic goods. His empirical estimates supported the assumption that goods were not perfect substitutes and that imports were closer substitutes for each other than for domestic goods.

In Bergstrand (1989, 1990) he departed even further from the HO model by assuming Dixit-Stiglitz (1977) monopolistic competition, and therefore product differentiation among firms rather than among countries. This was imbedded, however, in a two-sector economy in which each monopolistically competitive sector had different factor proportions, thus being a hybrid of the perfectly competitive HO model and the one-sector monopolistically competitive model of Krugman (1979). In the first paper Bergstrand used this framework to derive yet again a version of the gravity equation, and in the second he examined bilateral intraindustry trade.

Bergstrand's later work therefore serves to bring together the earlier Armington-based approaches to deriving the gravity equation with a second strand of literature in which gravity equations were derived from simple monopolistic competition models. Almost from the start of the new trade theory's attention to such models, it was recognized that they provided an immediate and simple justification for the gravity equation.[2] Indeed, Helpman (1987) used this correspondence between the gravity equation and the monopolistic competition model as the basis for an empirical test of the latter. That is, he interpreted the close fit of the gravity equation with bilateral data on trade as supportive empirical evidence for the monopolistic competition model. For this to be correct, of course, it would need to be true, as Helpman apparently believed, that the gravity equation does not also arise from other models. He remarked that "the factor proportions theory contributes very little to our understanding of the determination of the volume of trade in the world economy, or the volume of trade within groups of countries" (63), and he went on to demonstrate geometrically that the volume of trade under FPE in the $2\times2\times2$ HO model is independent of country sizes.[3] Helpman was, I would like to think, in good company. No less an authority than Deardorff (1984, 500–504) noted several of the empirical regularities that are captured in the gravity equation and pronounced them paradoxes, inconsistent with, or at least not explainable by, the HO model.

Helpman applied his test to data on trade of the Organization for Economic Cooperation and Development (OECD) countries, where most would agree that monopolistic competition is plausibly present. Hummels and Levinsohn (1995) decided to attempt a sort of negative test of the same proposition by looking for the same relationship in the trade among a much wider variety of countries, including ones where monopolistic competition is less plausibly a factor. To their surprise, they found that the test worked just as well for that group of countries, thus leading one to suspect that perhaps the relationship represented by the gravity equation is more ubiquitous, and not unique to the monopolistic competition model. It might be thought that the work by Anderson and Bergstrand cited above would have already suggested this, since they derived gravity equations from a variety of models other than the monopolistic one that Bergstrand eventually incorporated into his analysis. But in fact the versions of the gravity equation that Anderson and Bergstrand obtained were somewhat complex and opaque, and it was not obvious that they would lead to the success of the very simple gravity equation tested by Helpman.

My point in this paper, of course, is that one can get essentially this same

2. One such was apparently Krugman (1980), cited in Helpman (1987).

3. This argument appeared first in Helpman and Krugman (1984). I would argue that Helpman's locus for comparisons, which are along straight lines parallel to the diagonal of a Dixit-Norman-Helpman-Krugman factor allocation rectangle, is inappropriate. Along these straight lines, the differences in relative factor endowments of the two countries also change, becoming more pronounced (and leading to greater trade) at the same time that countries are becoming more different in size (leading to less trade). A better comparison would have been along a locus for which the percentage difference in factor endowment ratios remains constant. This would be a curve bowed out from the diagonal of the box, and along this curve the trade volume would be largest where country incomes are equal, just as in the gravity equation.

simple gravity equation from the HO model properly considered, both with frictionless and with impeded trade. This does not mean that the empirical success of the gravity model lends support to the HO model, any more than it does to the monopolistic competition model. For reasons I have already indicated, I suspect that just about any plausible model of trade would yield something very like the gravity equation, whose empirical success is therefore not evidence of anything, but just a fact of life.

1.3 Frictionless Trade

Consider now an HO model with any numbers of goods and factors. In fact, for most of what I will say in this section,[4] the argument is more general and could apply to any perfectly competitive trade model with homogeneous products, including a Ricardian model, a specific-factors model,[5] a model with arbitrary differences in technology, and so forth. For this model, consider a frictionless trade equilibrium—that is, an equilibrium with zero transport costs and no other impediments to trade—with each country a net exporter of some goods to the world market and a net importer of others. This equilibrium need not be unique, as it will not be in the HO model with FPE and more goods than factors. If the model is HO, then there may be FPE among some or all countries, but there need not be. We need merely have some vectors of production, consumption, and therefore net trade in each country that are consistent with maximization by perfectly competitive producers and consumers in all countries, facing the same prices (due to frictionless trade) for all goods, the vectors being such that world markets clear.

It is customary to note that patterns of bilateral trade are not determined in such a model, and indeed they are not. But the reason for this indeterminacy is itself important: both producers and consumers are indifferent, under the assumption of frictionless trade and homogeneous products, among the many possible destinations for their sales and sources for their purchases. Therefore, while it is true that a wide variety of outcomes is possible, we can get an idea of the average outcome by just allowing choices among indifferent outcomes to be made randomly.

Thus, having already found the equilibrium levels of production and consumption, let the actual transactions be determined as follows: producers in each industry put their outputs into a world pool for their industry; consumers then choose randomly their desired levels of consumption from these pools. If consumers draw from these pools in small increments, then the law of large numbers will allow us to predict quite accurately what their total choices will be by using expected values. In general, these expected values will be appro-

4. The only exception is the penultimate paragraph of this section, where bilateral trade is related to per capita incomes using an assumption about preferences and factor intensities of goods.

5. Of course the specific-factors model is just a special case of the HO model with many goods and factors.

priate averages of the wide variety of outcomes that are in fact possible in the model.

1.3.1 Homothetic Preferences

All of this works extremely simply if preferences of consumers everywhere are identical and homothetic, which I will now assume as a first case. Let x_i be country i's vector of production and c_i its vector of consumption in a frictionless trade equilibrium with world price vector p.[6] Its income is therefore $Y_i = p'x_i = p'c_i$, where I also assume balanced trade so that expenditure equals income. Now consider the value of exports from country i to country j, T_{ij}. With identical, homothetic preferences all countries will spend the same fraction, β_k, of their incomes on good k, so that country j's consumption of good k is $c_{jk} = \beta_k Y_j / p_k$. Drawing randomly from the world pool of good k, to which country i has contributed the fraction $\gamma_{ik} = x_{ik}/\Sigma_h x_{hk}$, country j's purchases of good k from country i will be $c_{ijk} = \gamma_{ik}\,\beta_k Y_j/p_k$. Let $x_k^w = \Sigma_i x_{ik}$ be world output of good k. Note that, with identical fractions of income being spent on good k by all countries, that fraction must also equal the share of good k in world income, Y^w: $\beta_k = p_k x_k^w / Y^w$. The value of j's total imports from i is therefore

$$
\begin{aligned}
T_{ij} &= \sum_k p_k c_{ijk} = \sum_k \gamma_{ik}\beta_k Y_j \\
&= \sum_k \frac{x_{ik}}{x_k^w}\frac{p_k x_k^w}{Y^w} Y_j = \sum_k p_k x_{ik}\frac{Y_j}{Y^w} \qquad (2)\\
&= \frac{Y_i Y_j}{Y^w}.
\end{aligned}
$$

Thus with identical, homothetic preferences and frictionless trade, an even simpler gravity equation than (1) emerges immediately, with constant of proportionality $A = 1/Y^w$. Distance, of course, plays no role here since there are no transport costs, and I will call equation (2) the simple frictionless gravity equation. To get this, all that is needed is to resolve the indeterminacy of who buys from whom by making that decision randomly.

1.3.2 Arbitrary Preferences

If preferences are not identical and/or not homothetic, then the equilibrium may have each country spending a different share of its income on each good, and the simple derivation above does not work. Let β_{ik} now be the share of its income that country i spends on good k in the equilibrium, and also let α_{ik} be the share of country i's income that it derives from producing good k. The first and second equalities of equation (2) still hold, but with β_k replaced by β_{ik}. The value of world output of good k is $p_k x_k^w = \Sigma_i \alpha_{ik} Y_i$, and therefore the fraction of world output of good k that is produced by country i is $\gamma_{ik} = \alpha_{ik} Y_i / \Sigma_h \alpha_{hk} Y_h$.

6. All vectors are column vectors unless transposed with a prime.

Country j, again drawing randomly from the pool for good k an amount equal to its demand $\beta_{jk}Y_j$, will get that fraction from country i. Thus the value of sales by country i to country j of good k will be

$$T_{ijk} = \frac{\alpha_{ik}Y_i}{\sum_h \alpha_{hk}Y_h}\beta_{jk}Y_j. \tag{3}$$

Summing across goods k, we get

$$T_{ij} = \sum_k T_{ijk} = \sum_k \frac{\alpha_{ik}Y_i}{\sum_h \alpha_{hk}Y_h}\beta_{jk}Y_j = Y_iY_j\sum_k \frac{\alpha_{ik}\beta_{jk}}{p_k x_k^w}. \tag{4}$$

This is not the gravity equation, since the summation could be quite different for different values of i and j. As an extreme example, if country i happens to specialize completely in a good that country j does not demand at all, then T_{ij} will be zero regardless of Y_i and Y_j.

However, it is possible to simplify equation (4) further if one can assume that the fractions that exporters produce and that importers consume are in some sense unrelated. Let $\lambda_k = p_k x_k^w / Y^w$ be the fraction of world income accounted for by production of good k. Then

$$T_{ij} = \frac{Y_iY_j}{Y^w}\sum_k \frac{\alpha_{ik}\beta_{jk}}{\lambda_k}. \tag{5}$$

Clearly, since each country's good shares of both production (α_{ik}) and consumption (β_{jk}) sum to one, this will reduce to the simple frictionless gravity equation (2) if either the exporter produces goods in the same proportions as the world ($\alpha_{ik} = \lambda_k$) or if the importer consumes goods in the same proportion as the world ($\beta_{jk} = \lambda_k$, as was true in the case of identical, homothetic preferences), but not in general. If the λ_k were equal for all k, thus each being $1/n$ where n is the number of goods, we would also get back to equation (2) if α_{ik} and β_{jk} were uncorrelated. With goods having unequal shares of the world market, we can still get this if we define correlations on a weighted basis, using the λ_k as weights.

That is, let

$$\tilde{\alpha}_{ik} = \frac{\alpha_{ik} - \lambda_k}{\lambda_k}, \quad \tilde{\beta}_{jk} = \frac{\beta_{jk} - \lambda_k}{\lambda_k},$$

be the proportional deviations of country i's production shares and of country j's consumption shares from world averages. Then

$$\begin{aligned} \sum_k \lambda_k \tilde{\alpha}_{ik}\tilde{\beta}_{jk} &= \sum_k \frac{1}{\lambda_k}\left(\alpha_{ik}\beta_{jk} - \lambda_k\beta_{jk} - \lambda_k\alpha_{ik} + \lambda_k^2\right) \\ &= \sum_k \frac{\alpha_{ik}\beta_{jk}}{\lambda_k} - 1, \end{aligned} \tag{6}$$

and we can rewrite equation (5) as

$$T_{ij} = \frac{Y_i Y_j}{Y^w}\left(1 + \sum_k \lambda_k \tilde{\alpha}_{ik} \tilde{\beta}_{jk}\right). \tag{7}$$

This is the main result of this section of the paper. The sign of the summation in equation (7) is the same as the sign of the weighted covariance between $\tilde{\alpha}_{ik}$ and $\tilde{\beta}_{jk}$. Thus, if these deviations of exporter production shares and importer consumption shares from world averages are uncorrelated, then once again the simple frictionless gravity equation (2) will hold exactly.

Perhaps more importantly, equation (7) also states simply and intuitively when two countries will trade either more or less than the amounts indicated by the simple frictionless gravity equation. If an exporter produces above-average amounts of the same goods that an importer consumes above average, then their trade will be greater than would have been explained by their incomes alone. On the other hand, if an exporter produces above average what the importer consumes below average, their trade will be unusually low. These statements presume that the simple frictionless gravity equation describes what is "usual." This is in fact the case here, since across all country pairs (i, j) the average of bilateral trade is equal to what the simple frictionless gravity equation prescribes.

$$\begin{aligned}
\sum_{ij}\left(T_{ij} - \frac{Y_i Y_j}{Y^w}\right) &= \sum_{ijk} \frac{Y_i Y_j}{Y^w} \lambda_k \tilde{\alpha}_{ik} \tilde{\beta}_{jk} \\
&= \sum_{ik} \frac{Y_i}{Y^w} \tilde{\alpha}_{ik} \sum_j \left(Y_j \beta_{jk} - Y_j \lambda_k\right) \\
&= \sum_{ik} \frac{Y_i}{Y^w} \tilde{\alpha}_{ik} \left(\sum_j c_{jk} - \lambda_k Y^w\right) \\
&= 0
\end{aligned} \tag{8}$$

To sum up, with frictionless trade the values of bilateral trade are on average given by the simple frictionless gravity equation, $Y_i Y_j / Y^w$. If expenditure fractions differ across countries because preferences are not identical and/or not homothetic, then individual bilateral trade flows will vary around this frictionless gravity value. If one country tends to overproduce what another overconsumes, then exports of the former to the latter will be above that value, and if one tends to underproduce what another overconsumes, then these exports will be below that value.

It is important for these results that sales of a country to itself, T_{ii}, be included along with international trade. In this form the gravity equation holds on average even in the special case of countries who each demand only their own products. Their above average "exports" to themselves then offset their below average (zero) exports to each other to leave the average unaffected.

Combined with what we already know about the HO model and what we may suspect about preferences, this also leads us loosely to a corollary that I suspect could be made more formal with additional effort. Suppose that preferences are internationally identical but not homothetic, and suppose further that high-income consumers tend to consume larger budget shares of capital-intensive goods. Then capital-abundant countries will have higher than average per capita incomes and will therefore consume capital-intensive goods in disproportionate amounts. At the same time, from the HO theorem, they will also produce disproportionate amounts of these same goods. Therefore we would expect to find these countries trading more than average with each other and less than average with low-income labor-abundant countries. This is the same result that Markusen (1986) found in his "eclectic" model and for essentially the same reason. Although Markusen had increasing returns and monopolistic competition in his manufacturing sectors, these features served primarily to generate intraindustry trade. His volume-of-trade result was driven by a high income elasticity for capital-intensive goods.

Such a disproportionately high volume of trade among high-income countries happens to accord well with trade patterns in the real world. On the other hand, under the same circumstances the theory here also predicts that labor-abundant (hence poor) countries will trade disproportionately with each other as well. This is the same conclusion that Linder (1961) came to from a quite different theoretical model, but the empirical evidence in its favor is less clear.[7]

1.4 Impeded Trade

I turn now to the case of impeded trade, assuming instead that there not only exist barriers to trade, such as transport costs, but that these exist for every good. These barriers needn't be large, but I will assume them to be strictly positive on all international transactions. The case that I will consider will in addition have the property that every country produces and exports different goods. Indeed, this extreme specialization is the only property that I actually need in this section—the trade barriers are incidental.[8] I thought briefly that this case was the only one that could arise with positive transport costs, but I now realize that my thinking was flawed. I will nonetheless try to motivate the specialization assumption along the lines of that argument, but ultimately I can only claim to be considering a special case.

As mentioned in the introduction, the HO model has a striking implication in the presence of strictly positive transport costs: while in general the HO model permits equilibria with both FPE and non-FPE among groups of coun-

7. As I understand it, Jeffrey Frankel and co-authors have found in several studies, such as Frankel, Stein, and Wei (chap. 4 of this volume), that high-income countries trade disproportionately more than the gravity equation would suggest with all trading partners and not just among themselves, while low-income countries trade less.

8. Thus the results in this section would also obtain in an HO model with frictionless trade if factor endowments differed sufficiently to yield such specialization, as well as in a Ricardian model with specialization. They would also hold in any Armington model and any monopolistic-competition model, in both of which product differentiation in effect implies specialization.

tries, no two countries that have the same factor prices can trade with each other. The reason is that with identical factor prices (recall that the FPE theorem equates factor prices absolutely, not just relatively) they will have identical costs of production. With perfect competition neither country's producers could compete with domestic producers in the other's market, since the exporters would have to overcome the positive transport cost and domestic suppliers would not.

Now this is not a very appealing property of the HO model, I admit, and this by itself might be enough to make you prefer a model with some sort of imperfect competition. But it is a property of the HO model nonetheless, and I will take advantage of it. Since we do in the real world observe virtually every country trading with every other, if we are to give the HO model a chance to apply in the real world, we must assume unequal factor prices in each pair of countries.

Now suppose also that there are many more goods than there are factors, perhaps even an infinite number of goods as in Dornbusch, Fischer, and Samuelson (1977, 1980). If trade were frictionless, having unequal factor prices would severely limit the number of goods that any two countries could produce in common. With trade impediments this is no longer the case, since goods can become nontraded, and they can also compete in the same market if the difference in transport costs exactly equals the difference in production costs. But if transport costs for a given good are constant between any pair of countries (not varying with the amount transported), then I think the case can be made that only a negligibly small subset of all goods will be sold by any two countries to the same market. Thus for almost all trade, a country's consumers will be buying each good from only a single country's producers, either their own domestic industry or from the industry of a single foreign exporter.

This is not quite the same as saying that there exists only a single exporter of each good anywhere in the world, but that is nonetheless the case that I will consider. Indeed, I will go one step further and assume that each good is not only exported by only one country but is also produced only in that country. That being the case, the products of each country will be distinct in the eyes of consumers, not because of an Armington assumption that national origin matters, but because there really are different goods. One could argue that this is just as unrealistic as the case I dismissed above of countries not trading with each other at all, since for any industrial classification one observes production in multiple countries of goods that are classed the same. However, just as in the debate over the existence of intraindustry trade, where the phenomenon is sometimes argued to be an artifact of aggregation,[9] it may be that multiple producing countries may simply be producing different goods.

Suppose then that every good is produced by a different country in a particular international trading equilibrium. As long as we consider only that equilib-

9. See Deardorff 1984, 501, for a discussion.

rium, we can identify each good with the country that produces it and enter them into a utility function as imperfect substitutes. Let transport costs be of Samuelson's "iceberg" form, with the transport factor (one plus the transport cost) between countries i and j being t_{ij}. That is, a fraction $(t_{ij} - 1)$ of the good shipped from country i is used up in transport to country j.

With perfect competition, sellers from country i will not discriminate among markets to which they sell, and they will therefore receive a single price, p_i, for their products in all markets. Buyers, however, must pay the transport cost, and therefore the buyers' price in market j will be $t_{ij} p_i$.

What can we say about the pattern of bilateral trade? That depends on preferences, which I will assume first to be identical and Cobb-Douglas. That is, consumers in each country spend a fixed share, β_i, of their incomes on the product of country i. Let x_i be the output of country i. Country i's income, Y_i, is

$$(9) \qquad Y_i = p_i x_i = \sum_j \beta_i Y_j = \beta_i Y^w,$$

from which $\beta_i = Y_i / Y^w$. Trade can be valued either exclusive of transport costs (f.o.b.) or inclusive of transport costs (c.i.f.). On a c.i.f. basis we get immediately

$$(10) \qquad T_{ij}^{cif} = \beta_i Y_j = \frac{Y_i Y_j}{Y^w}.$$

With Cobb-Douglas preferences, therefore, we once again get the simple frictionless gravity equation for c.i.f. trade, with no role for transport costs or distance. On an f.o.b. basis, however, these flows must be reduced by the amount of the transport cost:

$$(11) \qquad T_{ij}^{fob} = \frac{Y_i Y_j}{t_{ij} Y^w}.$$

To the extent that transport cost is related to distance, this immediately gives a result very similar to the standard gravity equation (1), which includes distance.

This Cobb-Douglas formulation is nonetheless not very satisfactory, because the bilateral expenditures on international trade do not decline with distance. To allow for that to happen, and as the last model that I will consider, let preferences be instead CES. Let consumers in country j maximize the following CES utility function defined on the products of all countries i (including their own):

$$(12) \qquad U^j = \left(\sum_i \beta_i c_{ij}^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)},$$

where $\sigma > 0$ is the common elasticity of substitution between any pair of countries' products. Facing c.i.f. prices $t_{ij} p_i$ of the goods, j's consumers, maximizing this function subject to their income $Y_j = p_j x_j$ from producing x_j, will consume

(13) $$c_{ij} = \frac{1}{t_{ij}\,p_i} Y_j \beta_i \left(\frac{t_{ij}p_i}{p_j^I}\right)^{1-\sigma},$$

where p_j^I is a CES price index of landed prices in country j:

(14) $$p_j^I = \left(\sum_i \beta_i t_{ij}^{1-\sigma} p_i^{1-\sigma}\right)^{1/(1-\sigma)}.$$

Therefore the f.o.b. value of exports from country i to country j is

(15) $$T_{ij}^{fob} = \frac{1}{t_{ij}} Y_j \beta_i \left(\frac{t_{ij}p_i}{p_j^I}\right)^{1-\sigma}.$$

Note that the c.i.f. value of trade is this same expression multiplied by t_{ij}, which is therefore now decreasing in t_{ij} if $\sigma > 1$.

The parameter β_i is no longer country i's share of world income, as it was in the Cobb-Douglas case, so this does not reduce as easily to the standard gravity equation. However, if we let θ_i be country i's share of world income, we can relate it to β_i as follows, and then solve for β_i:

(16) $$\begin{aligned}\theta_i &= \frac{Y_i}{Y^w} = \frac{p_i x_i}{Y^w} \\ &= \frac{1}{Y^w}\sum_j \beta_i p_j x_j \left(\frac{t_{ij}p_i}{p_j^I}\right)^{1-\sigma} \\ &= \beta_i \sum_j \theta_j \left(\frac{t_{ij}p_i}{p_j^I}\right)^{1-\sigma},\end{aligned}$$

from which

(17) $$\beta_i = \frac{Y_i}{Y^w} \frac{1}{\sum_j \theta_j \left(\frac{t_{ij}p_i}{p_j^I}\right)^{1-\sigma}}.$$

Using this in equation (15) we get

(18) $$T_{ij}^{fob} = \frac{Y_i Y_j}{Y^w} \frac{1}{t_{ij}} \left[\frac{\left(\frac{t_{ij}}{p_j^I}\right)^{1-\sigma}}{\sum_h \theta_h \left(\frac{t_{ih}}{p_h^I}\right)^{1-\sigma}}\right].$$

To simplify this and facilitate interpretation, first select units of goods so that each country's product price, p_i, is normalized at unity. Then p_j^I becomes a CES index of country j's transport factors as an importer, what I will call its average distance from suppliers δ^S:

$$\delta_j^S = \left(\sum_i \beta_i t_{ij}^{1-\sigma} \right)^{1/(1-\sigma)}. \tag{19}$$

What matters for demand along a particular route is the transport factor t_{ij} relative to this average distance from suppliers, what I will call the relative distance from suppliers ρ_{ij}:

$$\rho_{ij} = \frac{t_{ij}}{\delta_j^S}. \tag{20}$$

With this notation, the trade flow in equation (18) becomes

$$T_{ij}^{fob} = \frac{Y_i Y_j}{Y^w} \frac{1}{t_{ij}} \left[\frac{\rho_{ij}^{1-\sigma}}{\sum_h \theta_h \rho_{ih}^{1-\sigma}} \right]. \tag{21}$$

This is the main result of this section of the paper. It says the following: if importing country j's relative distance from exporting country i is the same as an average of all demanders' relative distances from i, then exports from i to j will be the same as in the Cobb-Douglas case. That is, c.i.f. exports will be given by the simple frictionless gravity equation, while f.o.b. exports will be reduced below that equation by the transport factor from i to j, much as in the standard gravity equation with the transport factor (one plus transport cost) measuring distance. If j's relative distance from i is greater than this average, then c.i.f. (respectively f.o.b.) trade along this route will be correspondingly less than the simple frictionless (resp. standard) gravity equation, while if j's relative distance from i is less than this, trade will be correspondingly more. Since the transport factor for a country from itself is always unity and therefore less than any such average, countries' purchases from themselves will always be more than would appear warranted by the simple frictionless gravity equation.

The result also says that the elasticity of trade with respect to these relative distance measures is $-(\sigma - 1)$. Thus, the greater the elasticity of substitution among goods, the more trade between distant countries will fall short of the gravity equation and the more trade among close countries (and transactions within countries themselves) will exceed it.

Likewise, a general reduction in the transport factors themselves, such as might occur with an improvement in transportation technology, will pull trade closer to the amounts predicted by the simple frictionless gravity equation. This does not therefore mean that all bilateral trade flows will expand with a drop in transport costs. Rather, trade between distant countries will expand, while trade between close countries—neighbors—will contract, since the latter lose some of their advantage relative to distant countries. Of course a country is its own closest neighbor, and therefore purchases of a country from itself also contract. It follows that total international trade expands.

1.5 Conclusion

In this paper I have derived equations for the value of bilateral trade from two extreme cases of the HO model, both of which also characterize a variety of other models as well. The first case was frictionless trade, in which the absence of all barriers to trade in homogeneous products causes producers and consumers to be indifferent among trading partners, including their own country, so long as they buy or sell the desired goods. Resolving this indeterminacy with a random drawing, I derived expected trade flows that correspond exactly to the simple frictionless gravity equation whenever preferences are identical and homothetic. Generalizing the result to arbitrary preferences, I found that this gravity equation would still hold on average, but that individual trade flows would exceed or fall short of it depending on a weighted correlation between the exporter's and the importer's deviations from the world average supplies and demands. This in turn is suggestive of how particular nonhomotheticities in demand could interact with factor endowments and factor proportions to cause countries to trade excessively (compared to the simple frictionless gravity equation) with countries like themselves.

The second case considered was of countries that each produce different goods. This is also a possible equilibrium of the HO model, though of course it is a property as well of other models that have been used in the literature to derive the gravity equation, such as models with Armington preferences and models with monopolistic competition. Here I derived expressions for bilateral trade, first with Cobb-Douglas preferences and then with CES preferences. The former is almost too simple, yielding the simple frictionless gravity equation exactly for trade valued c.i.f. and the standard gravity equation, with division by a transport factor, for trade valued f.o.b. The CES case is more cumbersome, but it too reduces to something not all that different: bilateral trade flows are centered on the same values found in the Cobb-Douglas case, but they are smaller for countries that are a greater-than-average distance apart as measured by transport cost, and larger for countries that are closer than average. The latter includes purchases of a country from itself, which are increased above the Cobb-Douglas case by the greatest amount. The extent of these departures from the simple Cobb-Douglas gravity equation depends on the elasticity of substitution among goods, being larger the greater is that elasticity.

The lesson from all of this is twofold, I think. First, it is not all that difficult to justify even simple forms of the gravity equation from standard trade theories. Second, because the gravity equation appears to characterize a large class of models, its use for empirical tests of any of them is suspect.

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Comment Jeffrey H. Bergstrand

For over thirty years, international trade economists have evaluated empirically the economic determinants of bilateral international trade flows using the "gravity equation." As Alan Deardorff notes, Jan Tinbergen (1962) provided one of the first sets of estimates of a gravity equation applied to international trade flows. He estimated a version very similar to this paper's equation (1), but allowing the right-hand-side variables' coefficients to vary from unity. Over the years, numerous trade economists have used gravity equations to explain statistically international trade flows with various ulterior economic motives, including but not nearly limited to the papers referenced in Deardorff's study.

Theoretical Foundations

Those thirty years have also witnessed a frustrating fascination of trade economists with the gravity equation. The fascination stems from the consistently strong empirical explanatory power of the model, with R^2 values ranging from 65 to 95 percent depending upon the sample, which has been a persuasive motivation for its usage. For many years, the frustration has stemmed from a so-called absence of formal theoretical foundations. Yet as Deardorff notes in section 1.2, there are several formal theoretical foundations for the gravity equation in international trade. Anderson (1979), Helpman and Krugman (1985), and Bergstrand (1985, 1989, 1990) motivate the multiplicative gravity equation assuming either products differentiated (somewhat arbitrarily) by origin or monopolistically competitive markets with (well-defined) product differentiation. Baldwin (1994, 82) aptly summarizes the state of theoretical foundations for the gravity model: "The gravity model used to have a poor reputation among reputable economists. Starting with Wang and Winters (1991), it has come back into fashion. One problem that lowered its respectability was its oft-asserted lack of theoretical foundations. In contrast to popular belief, it does have such foundations."

Despite these theoretical foundations, part of the frustration of trade economists with the gravity equation has been a lack of willingness to motivate the gravity equation in the context of *classical* theories, especially the Heckscher-Ohlin framework.[1] Deardorff's paper addresses this concern carefully and adeptly.

Frictionless Models

Before focusing upon classical issues though, Deardorff first challenges the reader to think of international trade unconventionally. Whereas classical mod-

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1. As Deardorff notes, an exception is Bergstrand (1989), which imbeds monopolistically competitive product-differentiated markets in a two-sector economy with differing relative factor intensities between the two industries.

els typically consider export supplies as residual production after satisfaction of domestic demands, and conversely import demands as residual consumption beyond domestic production, Deardorff's first set of models—frictionless models—asks the reader to think of consumers and producers as being basically indifferent between domestic and foreign consumption and production, respectively. The essence of Deardorff's frictionless models can be reflected in the following simple framework. Suppose a country produced and consumed one homogeneous good under conditions of perfect competition. If the country's production and consumption were split into two equal economic "nations" (A and B), the representative consumer in A would be just as likely to consume A's output as B's output, and the representative producer in A would be just as likely to sell its output in the domestic market as in the foreign market.

The thrust of Deardorff's first frictionless model can be captured in three assumptions. (1) In each country, income (Y_i) equals production (PX_i) and consumption (PC_i), implying

(1) $$Y_i \equiv PX_i \equiv PC_i \equiv \sum_j^N PX_{ij}$$

and

(2) $$Y_j \equiv PX_j \equiv PC_j \equiv \sum_i^N PX_{ij},$$

where PX_{ij} is the flow of trade from i to j for all $i, j = 1, \ldots, N$ (including i to itself). (2) Tastes are identical across countries and homothetic, implying

(3) $$PX_{ij} = \gamma_i Y_j.$$

(3) The probability of country i exporting to country j is determined by the law of large numbers, implying

(4) $$\gamma_i = X_i / \sum_j^N X_j = Y_i / \sum_j^N Y_j = Y_i / Y^W,$$

where Y^W is world GDP ($\Sigma_j^N Y_j$) and is constant across country pairs. Substituting equation (4) into equation (3) yields a simple frictionless gravity equation:

(5) $$PX_{ij} = Y_i Y_j / Y^W.$$

This suggests that the gravity model can be derived under few assumptions and international trade can be generated without natural or acquired comparative advantages. Although one might consider little trade likely to be generated in this simple context, it is useful to see that the usual sources of international trade between nations—relative factor endowment differences or product diversity combined with increasing returns—are unnecessary for, but can be incorporated easily into, this simple trade framework.

Deardorff's model of frictionless trade under homothetic preferences in section 1.3 is not depicted quite so simply, because his ultimate motive in the section is rather to demonstrate that a slightly modified version of gravity equation (5) above is readily consistent with a Heckscher-Ohlin-type world, although one allowing nonhomothetic tastes. In the latter, consider a world with N countries where each country's share of production of commodity k can differ from the world's share (i.e., $p_k x_{ik}/Y_i = \alpha_{ik} \gtreqless \lambda_k = p_k x_k^W/Y^W$) and each country's relative demand for commodity k can differ from the world's relative demand (i.e., $p_k c_{jk}/Y_j = \beta_{jk} \gtreqless \beta_k = p_k c_k^W/Y^W$). Deardorff demonstrates that if the α_{ik} and β_{jk} are positively (negatively) correlated, then trade between countries i and j will exceed (fall short of) the simple frictionless gravity equation (5). The suggestion is that high real per capita income countries have high capital-labor ratios and tend to produce relatively capital-intensive goods. With nonhomothetic tastes, if capital-intensive goods are luxuries in consumption, high real per capita income countries will tend to trade more because of their tendency to produce and consume larger proportions of capital-intensive goods.

The main contributions of section 1.3 are to illustrate that the gravity model stands on its own, but also that Heckscher-Ohlin trade with nonhomothetic preferences can be generated within the context of and consistent with the gravity model. That the gravity model can evolve from an essentially Heckscher-Ohlin world (without any role for monopolistically competitive markets as in Bergstrand 1989) is a useful insight. Footnote 3 underscores the relevance of Deardorff's insight showing that—even in the absence of imperfectly competitive markets and increasing returns to scale—equal-sized countries in the Helpman and Krugman (1985) model (for instance, pp. 22–24) will tend to trade more *for given relative factor endowments.*

Models with Transportation Costs

What makes section 1.3's model interesting and novel is that the gravity model is derived in the *absence* of product differentiation, as in Leamer and Stern (1970). Section 1.4 considers trade in the *presence* of products differentiated by origin. While the first several pages attempt to motivate a rationale for why products are differentiated by origin from a non-factor-price-equalization context, the results in this section parallel earlier contributions to this literature more closely. The main result of section 1.4 is that the bilateral distance between i and j diminishes trade *and* that trade is influenced by the relative distance of importer j from exporter i (relative to other markets of i) relative to the average of all demanders' relative distances from i.

These notions have been present in one form or another in the earlier literature, similarly utilizing functions of constant elasticity of substitution; compare Anderson (1979) and Bergstrand (1985, 1989). For instance, Anderson showed that the trade flow was related to the bilateral i–j distance *and* to a complex "bracketed" term (as in this paper). In Anderson, the bracketed term was the ratio of a weighted average of importer j's distance from all markets to a weighted average of all countries' weighted average distances.

Bergstrand (1989) also used "iceberg" form transport costs as here. His gravity equation (12) can be rewritten to reflect the bilateral distance and the relative distance terms. Normalizing prices to unity and some algebraic manipulation yields trade flows as a function of (among other variables) the bilateral distance term (ignoring the industry superscript A in the original paper), $C_{ij}^{-(\sigma-1)/(\gamma+\sigma)}$, *and* the bilateral distance between i and j relative to the average distance of exporter i to all markets, $\{C_{ij}[\sum_n^N(1/C_{in})^{1+\gamma}]^{1/(1+\gamma)}\}^{-\gamma(\sigma-1)/(\gamma+\sigma)}$.

Deardorff's formulation is different because the relative distance term in his equation (21) isolates the distance of j from i relative to the average distance importer j faces for all suppliers from the average distance of i to all markets relative to all exporting countries. However, equation (21) is equivalent to equation (18), which specifies (after normalizing prices to unity) that the bracketed term reflect the distance between i and j relative to a weighted average of distances of exporter i to all markets, similar to Bergstrand (1989).

Nevertheless, an interesting common implication of all three studies is that the typical gravity equation specification with just the bilateral distance between i and j omits a potentially important explanatory variable, that is, the transport costs between i and j *relative* to some measure of "overall" transport costs.

It is interesting to note that the paper here, like Anderson's, normalizes all prices to unity to examine the importance of relative distances. However, suppose one considers the "frictionless" case where distances are normalized to unity but prices are not. In Deardorff's paper, equation (18) simplifies to

$$T_{ij}^f = \{Y_i Y_j / Y^W\} \, [(p_i/p_j^I)^{1-\sigma} / \sum_h \theta_h (p_i/p_h^I)^{1-\sigma}]. \tag{6}$$

Similarly, in the absence of the normalization of prices, Anderson's gravity equations would have included measures of relative prices. The importance of relative prices for suggesting the presence of product differentiation was emphasized in Bergstrand (1985). Bergstrand's model, under stronger assumptions, can be shown essentially equivalent to equation (6) above. Assuming the elasticities of substitution between imported and domestic products and that among imported goods are identical and the elasticities of substitution in production among export markets and between export and domestic are infinite (i.e., producers are indifferent between domestic and foreign markets and among foreign markets), the bilateral import demand function in Bergstrand can be written as

$$X_{ij}^D = a_i(Y_j/P_{ij})(P_{ij}/P_j^I)^{1-\sigma} \tag{7}$$

or

$$PX_{ij}^D = a_i Y_j (P_{ij}/P_j^I)^{1-\sigma} \tag{8}$$

The income constraint ensures

(9) $$Y_j = \sum_j^N PX_{ij}^S.$$

In general equilibrium, $PX_{ij}^S = PX_{ij}^D$, so equation (8) can be substituted into (9) to yield

(10) $$Y_i = \sum_j^N a_i Y_j (P_{ij}/P_j^I)^{1-\sigma}$$

or

(11) $$a_i = Y_i / \sum_j^N Y_j (P_{ij}/P_j^I)^{1-\sigma}$$

Substituting equation (11) into (8) yields

(12) $$PX_{ij} = Y_i Y_j [(P_{ij}/P_j^I)^{1-\sigma} / \sum_j^N Y_j (P_{ij}/P_j^I)^{1-\sigma}].$$

Equation (12) is similar to equation (6) above (and equation [18] in Deardorff) and suggests that relative prices, relative distances, relative tariffs, and so forth all matter in explaining departures of international trade flows from the basic gravity equation. Gravity equation practitioners have tended to ignore the importance of relative prices. Yet work by Kravis and Lipsey (1988) and Summers and Heston (1991) suggest that in cross-section prices differ considerably. In chapter 6 in this volume, by Charles Engel and John Rodgers, this view is lent further support. To the extent that measures of product differentiation, or distance of countries' products from their "ideal" variety (in the Hotelling-Lancaster sense), can be measured cross-sectionally, these factors need to be incorporated along with other asymmetries such as relative distance and relative tariffs in explaining departures from the basic frictionless gravity model. For completeness, in the case that goods are perfect substitutes ($\sigma = 1$), equation (12) simplifies to $PX_{ij} = Y_i Y_j / Y^W$, as in Deardorff's paper.

Conclusions

First, I agree with the paper's conclusion that simple forms of the gravity equation can be derived from standard trade theories. In fact, the author's first simple multiplicative frictionless gravity model can be derived *apart from* standard classical and the "new" trade theories. Second, I would agree more readily with the statement that the gravity equation appears to *be consistent with* a large class of models, rather than the gravity equation appears to "characterize" a large class of models. Third, the paper's conclusion that "its use for empirical tests of any of them is suspect" is correct; however, this statement is also misleading. Practitioners of the gravity equation over three decades have not—with the notable exception of Helpman (1987) and Hummels and Levinsohn (1995)—typically used the gravity equation to "test" trade theories. In most cases, the basic gravity model has been employed to capture statistically the bulk of trade variation to discern the marginal explanatory power of free trade pacts and/or exchange rate variability—additional variables appended to the basic frictionless model, without an aim to test one theory or another. Moreover, these contributions seem compatible with, and do not preclude, enhancements of the simple frictionless model to incorporate correlations between exporter relative factor endowments with importer relative goods demands, or the inclusion of distance and relative distance, as provided in this paper. Clearly, more work appears warranted on discerning further the gravity equation's empirical role in the context of international trade and trade theory, in step with the excellent enhancements and clarifications initiated in this paper.

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Comment Gene M. Grossman

This paper is vintage Alan Deardorff: crystal clear and elegant. Such papers are a pleasure to read but a nightmare to discuss.

Deardorff provides theoretical underpinnings for the so-called gravity equation, a simple equation explaining bilateral trade volumes as a function of the income levels of the two trading partners and the distance between them. This equation has been remarkably successful in innumerable empirical applications.

The "spin" that Deardorff puts on his findings is that the equation can readily be derived from a factor endowments model (such as Heckscher-Ohlin), whether there is universal factor price equalization or not. Thus, the empirical success of the gravity equation cannot be taken as evidence in favor of "new" trade models with imperfect competition and increasing returns to scale, as some previous authors may have suggested.

I will concentrate my remarks on the second part of the paper, as I don't find the first part (considering the case with no transport costs and factor price equalization) to be particularly compelling. When factor prices are equalized, production costs are the same in all countries. Then, as Deardorff notes, the location of production may be indeterminate and the gross volume of trade certainly will be so. He argues that, in this case, we may as well assume that consumers choose their supply sources randomly. In the event, the gravity equation drops out once we assume identical and homothetic preferences. But I would argue differently that, in cases of indeterminacy, ties must be broken by something. Perhaps this something is small, so small that we exclude it from our model. Nonetheless, it may well be systematic. Transport costs are just the candidate for tie-breaking here. And, indeed, this is the route that Deardorff follows in the second part of the paper.

I would give Deardorff's findings a slightly different spin. Only my emphasis would be different from his, as the points are ones that he himself makes. I would interpret his theoretical propositions as demonstrating that there is nothing at all surprising about finding that incomes Y_i and Y_j have substantial explanatory power in a regression for the bilateral trade volume T_{ij}. *Specialization* lies behind the explanatory power of these variables, and of course some degree of specialization is at the heart of any model of trade. Thus, the derivation of the gravity equation need not make reference to any particular trade model at all, as Deardorff points out in footnote 5. Specialization—and not new trade theory or old trade theory—generates the force of gravity.

The intuition is quite clear. If countries are specialized, then consumers in country *i* will want to buy things from country *j* that are not available, or not abundantly available, at home. The more things firms in *j* have to sell, the

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more things consumers in i will want to buy. So country j's output enters into determining the trade flow. Also, the more income country i's residents have, the more of country j's goods they will be able to buy. So country i's output enters into determining the trade flow. With *complete specialization* (each good produced in only one country) and *identical and homothetic preferences,* the elasticity of bilateral trade with respect to each partner's income level will be one. This is true no matter what supply-side considerations give rise to the specialization, be they increasing returns to scale in a world of differentiated products, technology differences in a world of Ricardian trade, large factor endowment differences in a world of Heckscher-Ohlin trade, or (small) transport costs in a world of any type of endowment-based trade.

So I agree that there is nothing surprising about the statistical significance of log Y_i and log Y_j in a regression for log T_{ij}, nor that their coefficients are often found to be close to one. I also agree that there is nothing surprising about the estimated *sign* of the coefficient on log D_{ij} (the distance between countries i and j, in the same regression). What I do find surprising is the *size* of the estimated coefficient on the distance variable.

McCallum (1995) provides an interesting recent example. He estimates trade flows between and among different provinces of Canada and states in the United States. The estimated coefficients on the log of income in the exporting region is 1.21, that on the log of income in the importing region is 1.06. Both are in keeping with the gravity predictions. But the coefficient on the log of distance in McCallum's regression is -1.42. This means that two regions separated by 500 miles will, all also equal, trade more than 2.67 times as much as two regions separated by 1,000 miles. In the same spirit, Leamer's estimates (1993) imply that in 1985 West Germany's trade with a partner country located 1,000 miles away was on average 4.7 times as great as that with a country of similar income located 10,000 miles away. In a world of modest transport costs, these findings are unexpected to me.

At least as surprising are the recurrent findings that countries trade so much with themselves. Trefler (1995) reports that the net factor content of trade for thirty-three countries accounting for three-quarters of world trade is an order of magnitude smaller than what would be predicted based on observed differences in their factor endowments. McCallum finds, even more strikingly, that trade between two provinces in Canada is more than twenty times larger than trade between one of these provinces and a similarly sized state in the United States located the same distance away!

Deardorff provides one possible explanation for the large coefficient on log D_{ij} (though not for the overriding importance of national boundaries, after controlling for distance). If all pairs of goods have a constant elasticity of substitution σ, and if transport costs are of the "iceberg" variety, then the coefficient on the log t_{ij} (the ratio of shipments to arrivals) in a regression explaining f.o.b. trade volume ought to be close to $-\sigma$. However, few would consider the "iceberg" formulation of shipping costs as anything more than useful trick for models with constant demand elasticities, and possibly a good approximation to the technology for shipping tomatoes.

Suppose instead that to ship a unit of country i's output to country j has a constant cost τ_{ij}. This cost reflects both the type (and average weight) of the goods in which country i is specialized, and the distance between between i and j. Suppose further that consumers worldwide have Cobb-Douglas preferences and that τ_{ij} is related to weight and distance according to $\tau_{ij} = w_i D_{ij}^{\alpha}$, where w_i measures the per unit weight (and other characteristics relevant for shipping expense) of country i's output. Then, according to my calculations,

$$\frac{d \log T_{ij}^{f}}{d \log D_{ij}} = -\alpha \left(\frac{\tau_{ij}}{p_i + \tau_{ij}} \right).$$

I suspect that shipping costs are no more than perhaps 5 percent of the value of traded goods, on average. A plausible value for α is perhaps 0.6. So the coefficient on D_{ij} ought to be less than -0.03. Elasticities of substitution above unity would raise this somewhat, but it is hard to see how one can get to -1.42 by this route.

All this leads me to believe that something is missing from our trade models, be they of the Heckscher-Ohlin or Dixit-Stiglitz-Krugman variety. It seems we need models where distance (and common polity, and common language, and common culture) play more of a role. I suspect this is a model with imperfect information, where familiarity declines rapidly with distance. Perhaps it is a model with very localized tastes (as in Trefler's "home bias" [1995]), which are historically determined and change only slowly with experience. Perhaps it is a model where distribution networks play a more central role. In any event, while Deardorff can give us a convincing explanation for the existence of gravitational forces in trade, he cannot tell us why these forces are so strong.

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