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The Missing Globalization Puzzle: Evidence of the Declining Importance of Distance

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Globalization can be characterized as the rapid increase in international trade spurred by advances in technology that have decreased the cost of trade. As costs have declined, so too, it would seem, should the estimated distance coefficient in the gravity model of bilateral trade. But a standard empirical result is that these estimated coefficients have been broadly stable, a result that might be called the "missing globalization puzzle." In contrast to results from the literature, we find evidence of globalization reflected in the estimated coefficients on distance in both cross-section and panel data. Our estimation procedures fully incorporate the information contained in observations where bilateral trade is zero and hence do not suffer from the potential estimation bias when observations where bilateral trade is zero are arbitrarily excluded from the sample. [JEL F10, F15]
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Globalization has many meanings. For our purposes, globalization can be characterized as the rapid increase in international trade spurred by advances in technology that have decreased the cost of trade, where the latter is broadly defined to include not just the cost of transportation but also the cost of search, information, communication, and so on. Globalization is sometimes caricatured by the phrase "the world is getting smaller," implying that it is mainly about the exchange of ideas, information, and products between countries previously thought of as being distant, rather than exchange between nearby countries. With technological advances such as the Internet, for example, the cost for an importer or manufacturer to obtain information about possible suppliers on the other side of the globe has declined substantially. Today it is virtually costless to call anywhere in the world using Internet long-distance facilities, whereas as recently as in 1990 the cost of a 3-min telephone call from New York to London was $3.32 and in 1930 it was $244.65. So globalization is closely associated with the notion that distances are less a barrier now than before.

It seems intuitive, therefore, that globalization would be reflected in the estimated coefficients on distance in the gravity model because distance is a proxy for all trade-related costs. As these costs have declined over time, so too, it would seem, should the estimated distance coefficients. But the distance coefficient in theoretical gravity models is a function of the ratio of the marginal cost of trade with respect to distance to the average cost of trade, rather than a simple function of trade costs. This means that even if globalization is a reflection of declining trade costs, this fact alone has no implication for the estimated coefficients on distance in gravity models: the estimated coefficients on distance would decline only if marginal costs have fallen faster than average costs. Although the available data on the evolution of trade costs do not distinguish between marginal and average costs, we argue that there is an a priori reason to believe that the marginal cost of trade with respect to distance has fallen faster than average costs. We also provide indirect support for this a priori argument with empirical evidence suggesting that changes in the estimated distance coefficients reflect movements mainly in marginal costs rather than in fixed costs.

Most empirical gravity models show no evidence of a declining distance coefficient. Equations estimated on 1970s or 1980s data, or even on data for earlier periods, look pretty much the same as those estimated on more recent data. Leamer and Levinsohn (1997, pp. 1387–88) summarize the empirical evidence: "… it seems appropriate to mention that the effect of distance on trade patterns is not diminishing over time. Contrary to popular impression, the world is not getting dramatically smaller." We refer to this well-established empirical result of a relatively stable distance coefficient as the missing globalization puzzle.

This paper takes a fresh look at globalization in the context of the gravity model. We make contributions in three areas. First, we show that a nonlinear specification of the gravity model has important advantages over the standard log-linear specification, most notably the ability to include observations where bilateral trade is zero, as emphasized by recent research (Anderson and van Wincoop, 2004; Helpman, Melitz, and Rubinstein, 2007; and Silva and Tenreyro, 2006). Second, we present nonlinear and log-linear results based on the standard specification of the gravity model in the literature and on the specification proposed by Anderson and van Wincoop (2003). And third, we estimate the gravity model on panel data based on a number of estimation procedures in addition to the nonlinear specification that also incorporate the information in the zero observations.

We find evidence of globalization. Our nonlinear estimates of the gravity model on cross-section data show a trend decline in the absolute value of the estimated coefficients on distance and on some other variables related to geography. And most of our panel nonlinear estimates confirm a statistically significant decline in these estimated distance coefficients. In addition, the magnitudes of the estimated distance coefficients in our preferred nonlinear specifications are closer to theoretical priors than are those in the literature. We also confirm that the standard log-linear specification does not yield evidence of globalization. This, together with our panel results based on alternative estimation procedures, suggests that the source of our differences with the existing literature is the ability of our nonlinear specification to include observations where bilateral trade is zero. The standard log-linear specification arbitrarily excludes these observations, resulting in potentially biased and inconsistent parameter estimates, and is very sensitive to various ad hoc methods used in the literature to deal with the "problem" of zero observations.

I. Globalization and the Gravity Model

In its simplest form (Deardorff, 1998), the gravity model relates bilateral trade to the economic mass of the two countries and barriers to trade:

$$Trade_{ij} = (Y_i Y_j)^{\alpha} C_{ij}^{\theta}, \tag{1}$$

where $Trade_{ij}$ is trade between country i and country j, Y is GDP, and C_{ij} is barriers to trade. Time subscripts are omitted for simplicity. Trade is expected to be negatively related to trade barriers ($\theta < 0$) and positively related to economic mass ($\alpha > 0$), with theoretical derivations indicating a unitary elasticity of trade with respect to economic mass ($\alpha = 1$).[1]

Our focus is on trade barriers, which can be expressed in general form as

$$C_{ij} = C_{ij}(d_{ij}, m_{ij}, f_i, f_j, f_{ij}), \tag{2}$$

where d_{ij} is costs related to distance between the trading partners, for example, communication and transportation costs, which can be proxied by how far the two countries are from each other, whether they share a common border, and how large each country is; m_{ij} is costs determined by the nature of the goods traded, which are typically not modeled explicitly but instead

[1] We omit for simplicity the constant of proportionality in Equation (1); it is incorporated in the barriers to trade function below.

captured in the constant term (Rauch, 1999); and f_i, f_j, and f_{ij} are other country-specific and country-pair-specific costs affecting trade, such as tariffs, cultural and legal barriers or similarities, port handling, and customs verification.

One aspect of distance emphasized in theoretical derivations of the gravity model is the distance of the two trading partners relative to the rest of the world (Deardorff, 1998; and Anderson and van Wincoop, 2003). The more remote a pair of countries is from the rest of the world, the lower the cost of trading with each other. As a proxy for these costs, Wei (1996) and Frankel and Wei (1998) propose a measure of remoteness defined as the GDP-weighted distance to all other trade partners:

$$R_i = \sum_j w_j D_{ij}, \tag{3}$$

where D_{ij} is the geographical distance between country i and country j, and $w_j = Y_j / \sum_i Y_i$ for all i; the calculation is done for $i \neq j$, and similarly for country j. Anderson and van Wincoop (2003) have recently proposed an alternative proxy for these relative costs, which they call "multilateral resistance." The multilateral resistance terms, which are functions of unobserved equilibrium price indices, are estimated by Anderson and van Wincoop through a nonlinear iterative procedure, but they note that a more straightforward approach is to estimate the gravity model with fixed effects—the approach we adopt below. Although Anderson and van Wincoop question the theoretical basis for other measures of relative distance, Harrigan (2003) argues that both the standard remoteness variable and the Anderson and van Wincoop approach are valid. Without taking a position on this issue, we present results based on both approaches for completeness and to facilitate comparisons with the literature.

Distance-related costs can also be viewed as the opportunity costs of domestic transactions vs. international transactions, suggesting that a measure of geographical size should be included as a proxy for "internal" distance. Obvious measures of country size include land mass and population. For larger countries, the cost of trading with themselves rather than with other countries is relatively low compared with the cost in smaller countries (Frankel, 1997). This implies that large, more self-sufficient countries will tend to trade less than small countries. Or, alternatively, that poorer countries—countries with larger populations for a given level of GDP—trade less than richer countries.

In line with the theoretical derivation, we specify the trade barrier function of Equation (2) in exponential form:

$$C_{ij} = D_{ij}^{\beta'} (R_i R_j)^{\gamma'} (P_i P_j)^{\delta'} e^{\kappa' + \lambda' A_{ij} + \varphi' L_{ij} + \sigma' F_{ij}}, \tag{4}$$

where D_{ij} is the geographical distance between countries i and j, R is remoteness, P is population, κ' is a constant, A_{ij} is a dummy variable equal to 1 if countries i and j share a common border and equal to zero otherwise, L_{ij} is a dummy variable equal to 1 if countries i and j share a common language, and F_{ij} is a dummy variable equal to 1 if countries i and j are members in the same free-trade agreement.[2] We expect β', $\delta' > 0$ and γ', λ', φ', $\sigma' < 0$. An alternative trade barrier function includes fixed effects rather than remoteness, as proposed by Anderson and van Wincoop (2003).

Substituting Equation (4) into Equation (1) yields the following gravity equation:

$$Trade_{ij} = (Y_i Y_j)^{\alpha} D_{ij}^{\beta} (R_i R_j)^{\gamma} (P_i P_j)^{\delta} e^{\kappa + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij}}, \tag{5}$$

where parameters β, γ, λ, φ, and σ are the products of θ (<0) and the respective parameters in Equation (4); β, $\delta < 0$; and γ, λ, φ, $\sigma > 0$.

The elasticity of trade with respect to distance (β) subsumes the elasticity of trade costs with respect to distance (β') along with the elasticity of trade with respect to trade costs (θ). Assuming a representative consumer maximizing a homothetic utility function, it can be shown that the elasticity of trade with respect to trade costs (θ) depends on the elasticity of substitution between all goods (ξ): $\theta = (1-\xi)$ (Deardorff, 1998; and Anderson and van Wincoop, 2003). Then, the coefficient on distance in a gravity equation (β) can be written as the product of the elasticity of trade costs with respect to distance (β') and the elasticity of trade with respect to trade costs $(1-\xi)$: $\beta = \beta'(1-\xi)$. From Equation (4), the elasticity of trade costs with respect to distance (β') is the ratio of marginal costs to average costs. The estimated coefficient on distance in the gravity model (β) then can be written as

$$\beta = (1 - \xi) \frac{\partial C_{ij}}{\partial D_{ij}} \bigg/ \frac{C_{ij}}{D_{ij}} = (1 - \xi) MC_{ij} / AC_{ij}. \tag{6}$$

How would the estimated coefficient on distance in the gravity model be expected to change over time? Assuming that consumer preferences and other parameters are stable over time, whether the distance coefficient falls or rises depends on whether marginal costs fall more or less than average costs over time. If marginal costs have declined more than average costs, the distance coefficient (β) in the gravity model should decline over time, and vice versa. The sign of this comparative static result is theoretically indeterminate because both marginal and average costs with respect to distance can be expected to decline with technological advancements in transportation and communication.

Unfortunately, the empirical evidence on trade-related costs does not distinguish between marginal and average costs, or between fixed and variable costs (Hummels, 1999a and 1999b and 2001; IMF, 2002; and

[2]Another candidate is a dummy variable for members of currency unions. Exploratory regressions indicate that exclusion of a currency union dummy has little effect on our estimated distance coefficients.

Anderson and van Wincoop, 2004). However, there is an a priori reason to believe that marginal costs with respect to distance have declined more than average costs. Theoretical gravity models imply that the complete elimination of trade costs would make distance irrelevant.[3] This means that the estimated distance coefficients would go to zero as the cost of trade goes to zero. From Equation (6), this can happen only if marginal costs go to zero faster than average costs. This limit result implies that the decline in trade costs associated with globalization should be reflected in declines over time in the (absolute value of) estimated coefficients on distance and other variables related to geography in empirical gravity models. Given that trade costs remain large (Anderson and van Wincoop, 2004)—that is, distance is not dead—any decline over the past few decades would be expected to be gradual, leaving the estimated distance coefficients significantly different from zero.

As noted, however, a key result from the empirical literature on gravity models, which are typically estimated on cross-country data for different time periods, is that the estimated coefficients on distance have been remarkably stable or even increasing over time, with most estimates varying between -0.5 and -1.0 or higher (Frankel, 1997; Frankel and Wei, 1998; Helliwell, 1998; Soloaga and Winters, 2001; Frankel and Rose, 2002; and Berthelon and Freund, 2004).[4] In their survey of the literature, Leamer and Levinsohn (1997) note that this result of a stable distance coefficient appears to be inconsistent with globalization.

A recent paper by Brun and others (2005) has looked again at this issue. By incorporating an augmented trade cost function that includes the cost of oil into their gravity model, they are able to reverse a rising distance elasticity, but only for industrial countries, not for the larger group of developing countries. As Anderson and van Wincoop (2004) note, it is not clear why introducing fuel costs has an impact only on the estimated distance coefficients for industrial countries, because trade costs of developing countries should be affected by oil prices in the same way as those of developed countries. Moreover, the quadratic specification in Brun and others (2005) constrains the distance coefficient to first increase before it declines, which seems inconsistent with the evidence on the evolution of trade costs.

In summary, most empirical gravity model studies find that the estimated distance coefficients are relatively stable, although, as discussed above, this result could simply reflect that marginal and average costs have fallen in tandem. Although we have argued on a priori grounds that marginal costs

[3]If transport costs are eliminated, the gravity model reduces to an equation relating trade to economic mass alone, called the frictionless gravity model by Deardorff (1998, see Equation (21)); see also Anderson and van Wincoop (2003, Equation (13)).

[4]Eichengreen and Irwin (1998) is one of the few studies reporting a decline in the estimated distance coefficient, from about -0.85 for 1949 to about -0.75 for 1964, perhaps reflecting the relatively long sample. Boisso and Ferrantino (1997) report distance coefficients that rise until the early to mid-1970s and fall thereafter.

have fallen more than average costs, implying that the estimated distance coefficients should have declined over time, data are not available to support this argument. Thus, the question of whether and how globalization shows up in the gravity model is essentially an empirical issue.

II. Equation Specification: To Log or Not to Log?

Our empirical work is based on stochastic versions of the nonlinear gravity Equation (5):

$$Trade_{ij} = (Y_i Y_j)^{\alpha} D_{ij}^{\beta} (R_i R_j)^{\gamma} (P_i P_j)^{\delta} e^{\mu_{ij}} + \varepsilon_{ij}, \text{ with} \tag{7}$$

$$\mu_{ij} = \kappa + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij},$$

and the Anderson and van Wincoop (2003) model with fixed effects replacing the remoteness variables:

$$Trade_{ij} = (Y_i Y_j)^{\alpha} D_{ij}^{\beta} (P_i P_j)^{\delta} e^{\mu_{ij}} + \varepsilon_{ij}, \tag{8}$$

with

$$\mu_{ij} = \theta_i + \kappa_j + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij},$$

where ε_{ij} is a well-behaved error term and θ_i and κ_j are fixed effects for countries i and j.

To allow comparisons with previous studies, we also estimate the more common log-linear specification of the gravity model. As with the nonlinear specifications, equations are estimated with either remoteness or fixed effects:[5]

$$\begin{aligned} \log Trade_{ij} = {} & \alpha \log Y_i Y_j + \beta \log D_{ij} + \gamma \log R_i R_j \\ & + \delta \log P_i P_j + \kappa + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} + \varepsilon_{ij}, \end{aligned} \tag{9}$$

$$\begin{aligned} \log Trade_{ij} = {} & \alpha \log Y_i Y_j + \beta \log D_{ij} + \delta \log P_i P_j + \theta_i \\ & + \kappa_j + \lambda A_{ij} + \varphi L_{ij} + \sigma Fij + \varepsilon_{ij}. \end{aligned} \tag{10}$$

Although the log-linear specification is a convenient way to address the problem of heteroscedasticity, we prefer the nonlinear specification for a number of reasons.[6] The first is that estimates based on the nonlinear

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[5]For simplicity, we use the same symbols to represent coefficients on the same variables in both the nonlinear and the log-linear specifications.

[6]A theoretical reason to prefer the nonlinear specification is that it implies that trade will go to zero as the size of either country goes to zero, which, as noted by Deardorff (1998, p. 9), must be correct; log-linear specifications do not have this property. In general, neither the nonlinear nor the log-linear specifications can predict zero trade (except in trivial cases). Helpman, Melitz, and Rubinstein (2007) present a theoretical and empirical model that does predict zero trade for some country pairs.

specification fully incorporate the information contained in observations where bilateral trade is zero.[7] This is important because many countries do not trade with each other: in our sample, the zero-valued observations account for almost 12 percent of the total in 1975 and almost 6 percent of all observations in 2000 (Table 1); in the larger sample used by Helpman, Melitz, and Rubinstein (2007), about 40–50 percent of the observations are zero. These zero-valued trade observations have economic meaning,[8] and a satisfactory empirical model should seek to explain, not omit, them (see Coe and Hoffmaister, 1999; Subramanian and Tamirisa, 2003; Helpman, Melitz, and Rubinstein, 2007; and Silva and Tenreyro, 2006). Omitting the zero-valued observations, which is necessary in a log-linear transformation of the gravity equation, represents a nonrandom screening of the data that can result in biased or inconsistent estimates.[9] Other ways of dealing with the "problem" of zero-valued observations in a log-linear specification may also bias coefficient estimates, as discussed below.

A second reason we prefer the nonlinear specification rather than the conventional log-linear specification is that the error term (ε_{ij}) and its logarithm generally are not statistically independent of regressors such as GDP or population. When the errors are heteroscedastic, as will generally be the case with such a large range of bilateral trade values (see Table 1), ordinary least squares (OLS) estimates of the log-linear transformation of Equation (8) are generally inconsistent, as emphasized by Silva and Tenreyro (2006).

A third reason has to do with the specification of the error term. The additive errors in the log-linear Equations (9) and (10) imply that the nonlinear specifications from which these log-linear equations have been derived include the error in the exponential terms rather than additively, as in

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[7]Other estimation methods that incorporate information in the zero observations include Tobit, pseudo-maximum likelihood, and the two-stage procedure proposed by Helpman, Melitz, and Rubinstein (2007), which incorporates a Tobit-like probit estimate in the first stage; we apply each of these methods below in our panel estimates. Estimation methods designed to deal with unobserved or missing variables, such as proposed by Heckman (1979), seem inappropriate given that the dependent variable is neither missing nor unobserved.

[8]The compilation methodology for trade statistics is discussed in IMF, *Direction of Trade Statistics*. Zero observations in *Direction of Trade Statistics* either represent bilateral trade reported by national authorities as explicitly zero or represent unreported bilateral trade (in some cases unreported trade in earlier periods is subsequently explicitly identified by national authorities as zero trade, suggesting that in these cases the missing trade is in fact zero trade). The compilation methodology is designed to identify obviously missing bilateral trade flows through partner information, estimation, or extrapolation. Moreover, a validation check compares the sum of bilateral trade with the independently reported aggregate trade levels reported in IMF, *International Financial Statistics*. In most cases, this check reveals virtually no differences or only minimal differences of 1–2 percent, suggesting that no significant amount of bilateral trade reported by the authorities is omitted. These procedures imply that observations reported as zero in *Direction of Trade Statistics* are either truly zero or extremely small.

[9]Greene (1981) shows that when the variables are distributed normally, the size of the bias is inversely proportional to the share of the sample included in the regression; that is, the greater the share of zero observations excluded, the greater the bias.

Table 1. Summary Statistics

	1975	1980	1985	1990	1995	2000
Trade ($M_{ij} + M_{ji}$)						
In billions of U.S. dollars						
Mean	0.24	0.57	0.58	1.08	1.58	2.02
Standard deviation	1.45	3.15	3.92	6.42	9.22	12.83
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	48.14	87.32	128.89	176.56	268.19	398.26
Zero-valued observations (in percent)	11.8	8.2	11.3	7.9	5.9	5.8
In logarithms						
Mean	−4.71	−4.08	−4.07	−3.64	−3.27	−3.16
Standard deviation	3.17	3.34	3.33	3.44	3.46	3.54
Minimum	−13.91	−14.56	−14.73	−16.91	−17.39	−17.79
Maximum	3.87	4.47	4.86	5.17	5.59	5.99
GDP						
In billions of U.S. dollars						
Mean	49.52	112.67	112.76	220.79	315.92	311.68
Standard deviation	105.54	222.83	258.75	505.13	783.72	752.39
Minimum	0.51	0.82	0.67	0.35	0.63	0.68
Maximum	1,635.18	2,795.55	4,213.00	5,803.25	7,400.55	9,872.93
In logarithms						
Mean	2.63	3.42	3.36	3.83	4.09	4.17
Standard deviation	1.67	1.72	1.77	1.92	2.00	1.95
Minimum	−0.68	−0.20	−0.40	−1.05	−0.46	−0.38
Maximum	7.40	7.94	8.35	8.67	8.91	9.20
Population						
In millions						
Mean	45.21	50.09	54.66	59.56	64.53	69.08
Standard deviation	128.53	139.96	151.72	165.26	177.69	189.09
Minimum	0.23	0.23	0.24	0.26	0.28	0.29
Maximum	908.16	987.05	1,058.51	1,143.33	1,211.21	1,265.83
In logarithms						
Mean	2.54	2.66	2.76	2.85	2.93	3.01
Standard deviation	1.49	1.50	1.50	1.50	1.50	1.50
Minimum	−1.48	−1.47	−1.43	−1.35	−1.27	−1.24
Maximum	6.81	6.89	6.96	7.04	7.10	7.14

Distance	*In kilometers*	*In logarithms*
Mean	8,074.30	8.79
Standard deviation	4,405.56	0.75
Minimum	4.15	1.42
Maximum	19,946.65	9.90

Note: See Appendix for data definitions and sources.

Equations (7) and (8). To understand the implications of this, consider two pairs of countries, one pair with large bilateral trade, such as Canada and the United States, and a second pair with small bilateral trade, such as Paraguay and Chad. In the log-linear specification of Equations (9) or (10), a 10 percent error would be equal to 0.1 for both pairs of countries, and hence least squares will place the same weight on reducing both errors, even though a 10 percent error for Canada-U.S. trade would be enormous (about $40 billion in 2000), whereas a 10 percent error for Paraguay-Chad trade would be negligible. In the nonlinear specifications, on the other hand, least squares will put relatively little weight on the negligible Paraguay-Chad error and more weight on reducing the large Canada-U.S. error, which, in our view, is clearly preferable.

In summary, coefficient estimates from a log-linear gravity model may be biased, inconsistent, or both, implying that no comfort can be taken in the large samples typically used in empirical gravity models. This is a first-order problem that should not be ignored or swept under the rug. The solution, in our view, is to avoid the self-inflicted wound of omitting the zero observations that the log-linear specification requires. A nonlinear specification does not require omitting the zero observations, although it does require addressing the problem of heteroscedasticity by calculating heteroscedastic-consistent standard errors.[10] Moreover, even though theoretical models are nonstochastic and provide no a priori reason to prefer one error specification over the other, the specification of the error term in the nonlinear model seems clearly preferable on empirical grounds.

For our purposes, it is particularly important to include the zero observations, because the decline over time in the number of pairs of countries that do not trade may itself be a reflection of globalization. This may be particularly important for the estimates of the distance coefficient because, in our sample, the average distance between pairs of countries that do not trade (8,720 km) is greater than the distance between countries that do trade (7,988 km). Evidence for globalization may be missing from conventional gravity models simply because some of the countries most affected by globalization are excluded from the analysis.

III. Cross-Section Estimation Results

Our data are summarized in Table 1. Bilateral trade and GDP are measured in nominal U.S. dollars, converted at market exchange rates. Because imports are generally better measured than exports, particularly for many developing countries, we define trade between countries *i* and *j* as the sum of *i*'s imports (*M*) from *j* plus *j*'s imports from *i*, $Trade_{ij} \equiv M_{ij} + M_{ji}$, implying that $Trade_{ij} \equiv Trade_{ji}$. Data definitions and sources are provided in the Appendix.

[10]Even if heteroscedasticity is unaddressed, the parameter estimates remain consistent, although the standard error estimates are biased.

Estimates of the gravity model on cross-section data for selected years during the past 25 years are reported in Tables 2 and 3. The regressions, both nonlinear and log-linear, include either a remoteness variable and a (unreported) constant (Table 2) or (unreported) fixed effects (Table 3).[11] The nonlinear models are estimated using nonlinear least squares on the full sample, including the zero-valued observations. Because residuals in this model are not normal, the nonlinear regressions are bootstrapped by blocks, as suggested by Freedman (1981) for models with non-normal, heteroscedastic errors. The log-linear model is estimated using the robust, heteroscedasticity-consistent estimator, excluding observations where the dependent variable is zero. The root-mean-squared errors normalized on the mean of the dependent variables suggest that the nonlinear model performs better than the log-linear model, particularly for the specification with fixed effects.

The most striking result in Tables 2 and 3 is the evidence of globalization in the nonlinear specifications. This evidence shows up in the estimated coefficients on distance, remoteness, and population, and is most vivid in the specifications with fixed effects.

- The strongest evidence is the decline in the estimated coefficients of distance in both nonlinear specifications. In the nonlinear specification with remoteness, the distance coefficients fall by more than one-third. The declines in the distance coefficients in the nonlinear specifications are in sharp contrast to the more or less standard result of stable or slightly increasing distance coefficients in the two log-linear specifications.
- The estimated coefficients on remoteness decline in both specifications.
- In the nonlinear models, the estimated coefficients on population are negative and decline over time to a level not significantly different from zero in 1995 in the equation with fixed effects, or in 2000 in the equation with remoteness. This is also true in the log-linear model with remoteness.[12]

There are a number of other noteworthy features of the estimation results in Tables 2 and 3:

- The level and the change in the estimated distance coefficients over time in the nonlinear specifications are much more consistent with theoretical priors than are results from the log-linear specification or from the literature, as discussed below.

[11]For the nonlinear Anderson and van Wincoop (2003) specification, in addition to the standard exclusion of a dummy variable (fixed effect) for one country in a regression with a constant, we excluded the fixed effects for the United States and China, which are highly correlated with income and population, respectively (with coefficients of correlation of about 0.8–0.9), to avoid multicollinearity. This was not necessary in the panel regressions reported below, which include fixed effects for all countries.

[12]Using land area instead of population makes almost no difference to either the cross-section or the panel results discussed below. We report results with population rather than land area to facilitate comparisons with other empirical studies.

Table 2. Cross-Section Estimates of Nonlinear and Log-Linear Models with Relative Costs Measured by Remoteness

	1975	1980	1985	1990	1995	2000
Nonlinear model						
Economic mass	0.93	0.99	1.10	0.89	0.79	0.74
	*(0.13)**	*(0.12)**	*(0.17)**	*(0.16)**	*(0.17)**	*(0.1)**
Distance	−0.53	−0.40	−0.41	−0.32	−0.29	−0.32
	*(0.21)**	*(0.14)**	*(0.18)**	*(0.15)*	*(0.11)**	*(0.12)**
Population	−0.15	−0.20	−0.22	−0.09	0.05	0.11
	*(0.11)**	*(0.12)**	*(0.14)**	*(0.14)*	*(0.17)*	*(0.14)*
Remoteness	1.21	1.15	1.28	0.87	0.85	0.46
	*(0.39)**	*(0.48)**	*(0.5)**	*(0.62)**	*(0.42)**	*(0.33)*
Adjacency	0.18	0.45	0.33	0.40	0.29	0.52
	(0.41)	*(0.21)*	*(0.22)*	*(0.28)*	*(0.32)*	*(0.17)**
Language	0.21	0.27	0.05	−0.33	0.15	0.03
	(0.28)	*(0.25)*	*(0.23)*	*(0.44)*	*(0.23)*	*(0.22)*
Free-trade agreement	0.32	0.66	1.28	0.78	0.96	0.77
	(0.43)	*(0.37)*	*(0.48)**	*(0.47)*	*(0.41)**	*(0.27)**
Number of observations	2,342	2,415	2,559	2,593	2,609	2,613
Adjusted R^2	0.88	0.86	0.92	0.87	0.88	0.91
RMSE	1.80	2.08	1.98	2.15	2.06	1.95
Log-linear model						
Economic mass	1.35	1.33	1.31	1.22	1.18	1.18
	*(0.03)**	*(0.03)**	*(0.02)**	*(0.02)**	*(0.02)**	*(0.02)**
Distance	−1.02	−1.01	−1.04	−0.92	−1.00	−1.08
	*(0.07)**	*(0.08)**	*(0.07)**	*(0.07)**	*(0.06)**	*(0.06)**
Population	−0.40	−0.33	−0.32	−0.23	−0.14	−0.10
	*(0.03)**	*(0.03)**	*(0.03)**	*(0.02)**	*(0.02)**	*(0.02)**
Remoteness	0.98	0.90	0.97	0.88	0.60	0.61
	*(0.15)**	*(0.16)**	*(0.15)**	*(0.15)**	*(0.12)**	*(0.14)**
Adjacency	0.16	0.14	0.19	0.54	0.41	0.36
	(0.26)	*(0.23)*	*(0.22)*	*(0.24)**	*(0.24)*	*(0.23)*
Language	0.98	0.84	0.64	0.75	1.01	0.85
	*(0.1)**	*(0.1)**	*(0.1)**	*(0.1)**	*(0.09)**	*(0.09)**
Free-trade agreement	0.75	0.39	0.74	0.45	0.32	0.30
	*(0.11)**	*(0.11)**	*(0.1)**	*(0.1)**	*(0.08)**	*(0.09)**
Number of observations	2,032	2,199	2,262	2,386	2,453	2,460
Adjusted R^2	0.68	0.69	0.71	0.73	0.80	0.78
RMSE	2.43	2.62	2.57	2.00	1.65	1.78

Note: The dependent variable is trade, which is defined using partner country import data. Data cover 73 countries, except for 1975, which includes 72 countries. An asterisk indicates significance at the 5 percent level. Bias-corrected standard errors are shown in italics for the nonlinear regressions, and robust errors are shown for the log-linear regressions. Root-mean-squared errors (RMSEs) are divided by the geometric mean of the dependent variable for the log-linear model and the arithmetic mean for the nonlinear model.

Table 3. Cross-Section Estimates of Nonlinear and Log-Linear Models with Relative Costs Measured by Fixed Effects

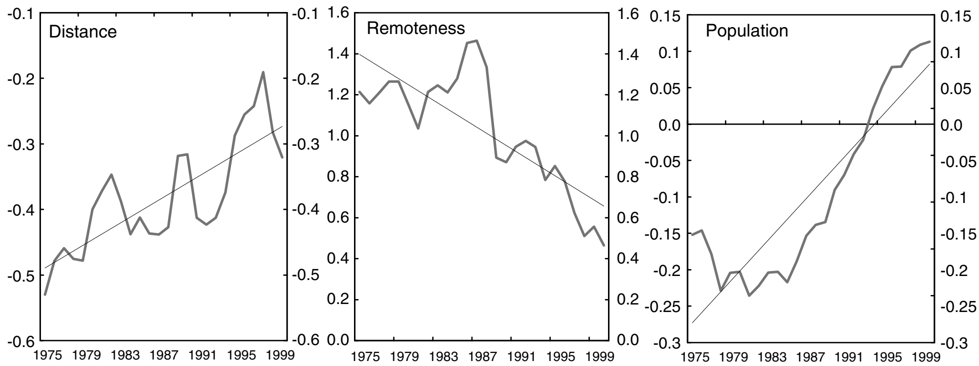
	1975	1980	1985	1990	1995	2000
Nonlinear model						
Economic mass	1.02	1.03	0.91	0.79	0.69	0.67
	(1.5)	*(0.08)**	*(0.09)**	*(0.10)**	*(0.08)**	*(0.06)**
Distance	−0.44	−0.51	−0.42	−0.33	−0.29	−0.35
	*(0.14)**	*(0.10)**	*(0.16)**	*(0.14)**	*(0.11)**	*(0.08)**
Population	−0.39	−0.28	−0.09	−0.03	0.13	0.13
	(2.53)	*(0.10)**	*(0.12)*	*(0.14)*	*(0.10)*	*(0.07)**
Adjacency	1.01	0.70	0.66	0.62	0.81	0.79
	*(0.31)**	*(0.22)**	*(0.26)**	*(0.46)**	*(0.30)**	*(0.34)**
Language	0.03	0.08	0.12	0.30	0.28	0.18
	(0.37)	*(0.29)*	*(0.27)*	*(0.27)*	*(0.20)**	*(0.20)*
Free-trade agreement	0.89	1.05	1.56	1.65	1.40	1.13
	*(0.34)**	*(0.34)**	*(0.45)**	*(0.40)**	*(0.36)**	*(0.30)**
Number of observations	2,324	2,415	2,559	2,593	2,609	2,613
Adjusted R^2	0.96	0.96	0.98	0.96	0.97	0.98
RMSE	1.03	1.09	1.05	1.13	1.02	0.91
Log-linear model						
Economic mass	1.40	1.22	1.03	0.97	0.88	0.84
	*(0.05)**	*(0.07)**	*(0.04)**	*(0.04)**	*(0.04)**	*(0.04)**
Distance	−0.95	−0.96	−1.01	−0.92	−0.98	−1.08
	*(0.07)**	*(0.07)**	*(0.07)**	*(0.07)**	*(0.06)**	*(0.07)**
Population	−0.47	−0.18	0.10	0.07	0.26	0.28
	*(0.07)**	*(0.08)**	*(0.06)*	*(0.06)*	*(0.05)**	*(0.06)**
Adjacency	0.43	0.37	0.38	0.68	0.65	0.58
	(0.24)	*(0.26)*	*(0.25)*	*(0.25)**	*(0.25)**	*(0.25)**
Language	1.07	0.95	0.88	0.87	0.97	0.92
	*(0.11)**	*(0.11)**	*(0.12)**	*(0.11)**	*(0.09)**	*(0.10)**
Free-trade agreement	0.62	0.43	0.48	0.60	0.56	0.45
	*(0.12)**	*(0.12)**	*(0.11)**	*(0.11)**	*(0.09)**	*(0.10)**
Number of observations	2,032	2,199	2,262	2,386	2,453	2,460
Adjusted R^2	0.76	0.78	0.77	0.79	0.84	0.83
RMSE	2.16	2.24	2.29	1.78	1.47	1.55

Note: See footnote in Table 2.

- In all regressions, the estimated coefficients on economic mass generally hover around unity, as suggested by theory. There is a trend decline in the estimated mass coefficients, although this decline may be bottoming out in the regressions for 1995 and 2000.
- There is no evidence of a decline in the estimated coefficients on the adjacency dummy. This is consistent with the view of globalization being reflected mainly in increased trade between distant countries rather than between neighboring countries.

The estimated coefficients on distance and the other geography variables from the cross-country regressions for the nonlinear specification with

Figure 1. Estimated Coefficients from Nonlinear Models for Individual Years, 1975–2000



Source: Authors' estimates.

remoteness are shown in Figure 1 for each year from 1975 to 2000 (graphs of the coefficients from the nonlinear specification with fixed effects are similar). Although the changes over time are not monotonic, there is a clear trend decline in the absolute value of the estimated coefficients on distance and on remoteness. There is a similar decline in the estimated coefficients on population, although here the estimated coefficients switch sign and become positive. We test whether these declines are statistically significant in the panel estimates discussed below.

Why Are the Nonlinear Estimates So Different from the Log-Linear Estimates?

The nonlinear regressions differ from the log-linear regressions common in the literature because the error specifications are different and because the nonlinear regressions include all observations whereas the log-linear regressions exclude observations where bilateral trade is zero, which may result in biased and inconsistent parameter estimates.

If the zero observations are excluded from the nonlinear regressions, the results are virtually identical to those reported in Tables 2 and 3, which means that the nonlinear specification does a good job of explaining observations where trade is zero or very small.[13] This could be because the country pairs with zero observations are statistically similar to country pairs with low-value observations, or because the least-squares procedure puts less weight on observations where trade is zero or small, or some combination of both.

Unlike the nonlinear regressions, the log-linear regressions are very sensitive to the inclusion of low or near-zero values of bilateral trade,

[13]This also implies that the nonrandom screening of the data implicit in the exclusion of the zero observations does not result in biased parameter estimates in the nonlinear specification.

suggesting potentially important biases are introduced by excluding the zero observations. The minimum value of bilateral trade in our data set is, in fact, quite small, at about \$20, roughly the amount of trade between Algeria and Malawi and between Algeria and Guyana in 2000. To test the sensitivity of the log-linear specification to small observations, we replaced the zero observations with near-zero values equivalent to less than \$1 in bilateral trade. When the log-linear regressions are run on this expanded data set, the R^2 for the regression for 2000 falls from 0.78 to 0.41. Moreover, the estimated coefficients on economic mass, remoteness, and distance increase (in absolute value) by about 60, 75, and 20 percent, respectively, and the coefficient on population increases by a factor of 3. Similar, albeit less dramatic, changes occur if the zero observations are replaced with values slightly below the lowest nonzero value for bilateral trade in the data set. Given that $\log x \to -\infty$ as $x \to 0$, it is not surprising that estimates based on the ad hoc adding of an arbitrary constant to the zero observations are very sensitive to the value of the constant. These experiments, which are similar to the way zero observations are handled in some gravity model studies (Wang and Winters, 1992; Anderson and Marcouiller, 2002; and Brun and others, 2005), suggest that the bias introduced by excluding the zero observations may be very significant in the log-linear specification.

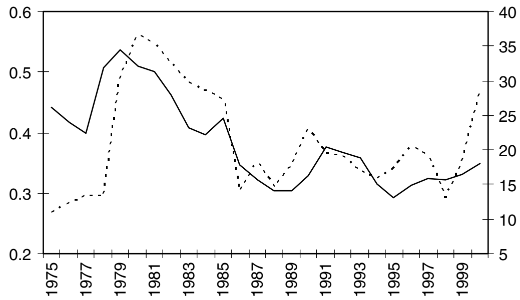
The Distance Coefficients

The estimated distance coefficients in the nonlinear specifications are substantially lower than those in the log-linear specification, which are similar to those found in the literature. Grossman (1998) argues that the values of the distance elasticity estimated in traditional models—he cites an estimate of -1.42—are implausibly high. His back-of-the-envelope calculation, which relates the distance coefficient to the elasticity of substitution between goods and the share of shipping costs in the total price of a traded product, suggests a value of only -0.03, although Grossman notes that an elasticity of substitution higher than unity would raise this estimate somewhat.[14] If the elasticity of transport costs with respect to distance estimated by Hummels (2001) of about 0.3 is combined with an elasticity of substitution between goods of about 2 to 3, the implied distance coefficient would be -0.3 ($= 0.3 \cdot (1–2)$) to -0.6, which is consistent with our estimates.[15]

[14]See also the discussion in Anderson and van Wincoop (2004, pp. 729–31). Grossman's Cobb-Douglas assumption and the implied elasticity of substitution between home and foreign goods of 1 is problematic because it would suggest a distance elasticity of zero.

[15]The relevant elasticity of substitution for this calculation is that between any pair of goods, whether domestically produced or imported. To our knowledge, estimates of this elasticity are not available, but it can be thought of as an average (with unknown weights) of the elasticity of substitution between domestic and imported goods and the elasticity of substitution among imports from different countries. Obstfeld and Rogoff (2000) suggest a consensus estimate of the elasticity of substitution between domestic and imported goods of 5–6; Saito (2004) estimates the elasticity of substitution among imports from Organization for Economic Cooperation and Development countries to be about 0.9.

Figure 2. Estimated Distance Coefficients and the Price of Oil
(Absolute value of distance coefficients from the annual nonlinear models with fixed effects, solid line, left scale; average oil price, U.S. dollars per barrel, dashed line, right scale)



Source: Authors' estimates.

Grossman's (1998) calculation also suggests that the distance elasticity should change over time in proportion to the change in the share of trade-related costs in total costs of traded products. The decline in our nonlinear estimates is broadly consistent with the stylized fact of about a 50 percent decline in the share of trade costs reported by Frankel (1997). Thus, both the level and the change in the estimated distance coefficients over time in our nonlinear specifications are more consistent with theoretical priors than are results from the standard log-linear specification in the literature.

Our estimates of the distance coefficients also appear to reflect mainly developments in marginal trade costs. One of the most important components of marginal costs is the price of oil. The absolute values of the estimated distance coefficients from the yearly 1975–2000 regressions are positively correlated over time with the price of oil (Figure 2), and the correlation is statistically significant. The estimated distance coefficients are thus larger in absolute value—more negative—when oil prices are high, suggesting that the estimated distance coefficients are capturing movements in marginal trade costs. By contrast, there is not a significant correlation between oil prices and the estimated distance coefficients from the log-linear regressions.

IV. Panel Estimation Results

Panel estimates of the gravity model are presented in Tables 4 and 5. The pooled data set is the 1975–2000 annual data used for the cross-section regressions for 73 countries (72 for 1975), resulting in about 66,000 observations. To test if changes in the estimated coefficients are statistically significant, key variables are allowed to shift in the 1980s and in the 1990s. Allowing for shifts in this way places less of a constraint on the data than specifying, for example, that the estimated coefficients decline in a linear or a quadratic way: a linear specification, for example, would impose that any

Table 4. Panel Estimates of Nonlinear and Log-Linear Models with Ten-Year Shifts[1]

	Nonlinear Model		Log-linear Model	
	With Remoteness	With Fixed Effects	With Remoteness	With Fixed Effects
Economic mass	1.03***	0.81***	1.35***	0.72***
	(0.05)	*(0.13)*	*(0.01)*	*(0.06)*
Economic mass × D (1980–89)	−0.08	−0.11	−0.04***	−0.03
	(0.06)	*(0.09)*	*(0.01)*	*(0.02)*
Economic mass × D (1990–2000)	−0.26*	−0.32**	−0.16***	−0.13***
	(0.05)	*(0.14)*	*(0.01)*	*(0.03)*
Distance	−0.50***	−0.58***	−1.01***	−1.01***
	(0.06)	*(0.13)*	*(0.03)*	*(0.09)*
Distance × D (1980–89)	0.09	0.07	0.06	0.04
	(0.07)	*(0.05)*	*(0.04)*	*(0.04)*
Distance × D (1990–2000)	0.16**	0.15*	0.03	0.07
	(0.06)	*(0.07)*	*(0.04)*	*(0.06)*
Population	−0.25***	−0.45	−0.39***	−0.56***
	(0.05)	*(0.50)*	*(0.01)*	*(0.16)*
Population × D (1980–89)	0.09*	0.07	0.08***	0.06***
	(0.05)	*(0.08)*	*(0.02)*	*(0.02)*
Population × D (1990–2000)	0.32***	0.27*	0.23***	0.19***
	(0.05)	*(0.14)*	*(0.05)*	*(0.03)*
Remoteness	1.40*		0.94***	
	(0.15)		*(0.07)*	
Remoteness × D (1980–89)	−0.43*		−0.19**	
	(0.17)		*(0.08)*	
Remoteness × D (1990–2000)	−0.70*		−0.22***	
	(0.17)		*(0.08)*	
Adjacency	0.40***	0.93**	0.14	0.43
	(0.12)	*(0.41)*	*(0.11)*	*(0.26)*
Adjacency × D (1980–89)	0.00	−20.60*	0.20	0.04
	(0.13)	*(9.23)*	*(0.13)*	*(0.13)*
Adjacency × D (1990–2000)	0.10	−6.80	0.26	0.17
	(0.13)	*(5.22)*	*(0.13)*	*(0.16)*
Language	0.03	0.11	0.82***	0.95***
	(0.05)	*(0.23)*	*(0.02)*	*(0.12)*
Free-trade agreement	0.66***	0.74	0.48***	
	(0.13)	*(0.39)*	*(0.02)*	
Fixed effects	No	Yes	No	Yes
Time effects	Yes	Yes	Yes	Yes
Zero-valued observations	Yes	Yes	No	No
Number of observations	66,159	66,159	59,975	59,975
Adjusted R^2	0.89	0.96	0.74	0.79

Source: Authors' calculations.

[1]The dependent variable is trade, which is defined using partner country import data. Data are for 1975–2000, for 73 countries, except for 1975, which includes 72 countries. *** (**, *) indicates significance at the 1 percent (5 percent, 10 percent) level. Bias-corrected standard errors are shown in italics for the nonlinear regressions, and robust standard errors are shown for the log-linear and two-stage regressions. Ten-year shift dummies, such as "D (1980–89)," are equal to 1 in 1980–89 and zero otherwise.

Table 5. Panel Estimates: Robustness to Alternative Estimation Methods[1]

	Pseudo-Maximum Likelihood			Tobit		Two-Stage Least Squares[2]	
	With remoteness	With fixed effects	With time-varying fixed effects	With remoteness	With fixed effects	With remoteness	With fixed effects
Economic mass	0.94***	0.78***	0.58***	2.24***	0.78***	0.79***	2.15***
	(0.04)	*(0.05)*	*(0.03)*	*(0.03)*	*(0.05)*	*(0.14)*	*(0.21)*
Economic mass × D (1980–89)	−0.02	−0.03	−0.02	−0.16***	0.01	0.02	−0.14***
	(0.03)	*(0.02)*	*(0.03)*	*(0.03)*	*(0.03)*	*(0.02)*	*(0.02)*
Economic mass × D (1990–2000)	−0.13***	−0.16***	−0.10***	−0.57***	−0.22***	−0.09***	−0.28***
	(0.05)	*(0.04)*	*(0.04)*	*(0.03)*	*(0.03)*	*(0.03)*	*(0.04)*
Distance	−0.63***	−0.58***	−0.60***	−1.52***	−1.43***	−0.43**	−2.30***
	(0.04)	*(0.05)*	*(0.05)*	*(0.07)*	*(0.06)*	*(0.16)*	*(0.22)*
Distance × D (1980–89)	0.002	0.04	0.06	0.47***	0.35***	−0.16**	0.46***
	(0.04)	*(0.03)*	*(0.04)*	*(0.08)*	*(0.07)*	*(0.07)*	*(0.08)*
Distance × D (1990–2000)	0.02	0.09**	0.10**	0.61***	0.56***	−0.09	0.21***
	(0.05)	*(0.04)*	*(0.05)*	*(0.08)*	*(0.06)*	*(0.07)*	*(0.06)*
Population	−0.22***	−0.97***	−1.24***	−0.79***	1.67***	−0.13*	−1.13***
	(0.05)	*(0.16)*	*(0.29)*	*(0.03)*	*(0.19)*	*(0.07)*	*(0.18)*
Population × D (1980–89)	0.03	0.03	0.19	0.14***	0.01	0.04	0.13***
	(0.04)	*(0.02)*	*(0.02)*	*(0.03)*	*(0.03)*	*(0.02)*	*(0.02)*
Population × D (1990–2000)	0.16*	0.17***	0.08**	0.51***	0.22***	0.12***	0.45***
	(0.08)	*(0.05)*	*(0.03)*	*(0.03)*	*(0.03)*	*(0.04)*	*(0.04)*
Remoteness	1.01***			1.48***		0.51*	
	(0.25)			*(0.15)*		*(0.26)*	
Remoteness × D (1980–89)	−0.10			−0.66***		0.03	
	(0.10)			*(0.18)*		*(0.09)*	
Remoteness × D (1990–2000)	−0.08			−0.97***		0.10	
	(0.17)			*(0.18)*		*(0.16)*	

Table 5 *(concluded)*

Adjacency	0.06	0.48***	0.59***	–0.18	0.62**	0.41	0.59***
	(0.21)	*(0.13)*	*(0.11)*	*(0.29)*	*(0.26)*	*(0.30)*	*(0.21)*
Adjacency × D (1980–89)	0.12	0.12	0.08	0.76**	0.28	–0.26	0.92***
	(0.09)	*(0.10)*	*(0.09)*	*(0.35)*	*(0.31)*	*(0.16)*	*(0.18)*
Adjacency × D (1990–2000)	0.29	0.2	0.06	0.70**	0.23	–0.27	1.16***
	(0.21)	*(0.16)*	*(0.13)*	*(0.34)*	*(0.30)*	*(0.23)*	*(0.22)*
Language	0.33**	0.28***	0.28	1.68***	2.16***	0.41***	2.03***
	(0.18)	*(0.10)*	*(0.10)*	*(0.04)*	*(0.05)*	*(0.14)*	*(0.20)*
Free-trade agreement	0.76***	0.76***	0.76***	1.17***	1.13***	–0.83**	3.89***
	(0.13)	*(0.13)*	*(0.13)*	*(0.06)*	*(0.06)*	*(0.34)*	*(0.44)*
Fixed effects	No	Yes	Yes	No	No	No	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-varying fixed effects	No	No	Yes	No	No	No	No
Zero-valued observations	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	66,159	66,159	66,159	66,159	66,159	59,975	59,975
Adjusted R^2				0.11[3]	0.14[3]	0.74	0.80
Log pseudo-likelihood	–37,529	–28,612	–28,147				

Source: Authors' calculations.

[1]The dependent variable is trade, which is defined using partner country import data. Data are for 1975–2000, for 73 countries except, for 1975, which includes 72 countries. *** (**, *) indicates significance at the 1 percent (5 percent, 10 percent) level. Bias-corrected standard errors are shown in italics for the nonlinear regressions, and robust standard errors are shown for the log-linear and two-stage regressions. Ten-year shift dummies, such as "D (1980–89)," are equal to 1 in 1980–89 and zero otherwise.

[2]Ordinary least squares estimator—the second stage of the two-stage estimation procedure proposed by Helpman, Melitz, and Rubinstein (2007). Zero-valued observations are taken into account in the first stage, probit regression, which is not reported.

[3]Pseudo-R^2.

decline be smooth and monotonic, eventually going to zero and becoming positive, whereas a quadratic specification as in Brun and others (2005) imposes that the estimated coefficients first increase and then decline, or vice versa, either of which seems inconsistent with the evidence that trade costs have declined but remain large.

Table 4 presents panel regressions based on the same nonlinear and log-linear specifications as the previous annual cross-section regressions (Tables 2 and 3), but allowing for parameter shifts. The R^2s are similar to the cross-section regressions, and the estimated coefficients are broadly comparable to the average of the cross-section estimates.[16] There is clear evidence of globalization in the nonlinear specifications: the estimated coefficients on distance, population, and remoteness decline in absolute value in the 1990s, and the estimated decline is statistically significant. As in the cross-section regressions, the estimated coefficient on adjacency does not decline. Panel estimates on the log-linear specification are similar to the cross-section results in that the estimated coefficient on distance is about twice as large as in the nonlinear estimates and does not decline over time, although the estimated coefficients on population and remoteness do decline.

To assess the robustness of the nonlinear panel results, Table 5 presents panel estimates based on three alternative estimation techniques, all of which incorporate the information in the zero observations. The first three regressions are estimated by the pseudo-maximum likelihood method suggested by Manning and Mullahy (2001) and Silva and Tenreyro (2006). The main difference between this method and the nonlinear least-squares estimator is that the latter implicitly gives higher weight to observations where bilateral trade is large, whereas the pseudo-maximum likelihood estimator treats all observations equally. The estimated distance and population coefficients decline significantly in the 1990s in the pseudo-maximum likelihood estimates with fixed effects and with time-varying fixed effects, although the estimated distance coefficient does not decline in the pseudo-maximum likelihood estimates with remoteness.

Tobit estimates and estimates based on the two-stage procedure applied by Helpman, Melitz, and Rubinstein (2007)—in which the zero-valued observations are taken into account in (unreported) first-stage probit regressions, with the second stage being OLS estimates of a log-linear specification—are also reported in Table 5. Although the estimated coefficients in these regressions are not elasticities, and hence cannot be compared to the coefficient estimates previously discussed (see McDonald and Moffitt, 1980), the estimated distance and population coefficients decline

[16]Ideally, panel estimations that are consistent with the Anderson and van Wincoop (2003) approach would include time-varying fixed effects. Except for the pseudo-maximum likelihood estimates reported in Table 5, this is computationally not feasible because including time-varying fixed effects would add an additional 1,500 coefficients to be estimated, whereas Stata does not allow more than 100 regressors in nonlinear estimations.

significantly in the 1980s and the 1990s except in the two-stage estimates with remoteness.

In summary, most of the panel estimates indicate a significant decline in the 1990s, and in some cases in the 1980s, in the estimated coefficients on distance and population.

V. Conclusions

We refer to the failure of most estimates of the standard gravity model of bilateral trade to reflect declining trade-related costs as the "missing globalization puzzle." This is most apparent in the estimated distance coefficients found in the literature, which show no evidence of a decline in absolute value over time. If anything, the consensus from the literature is that this coefficient has been constant, or even increasing, over time.

In contrast to previous gravity model studies, we find evidence of globalization or, more generally, of the declining importance of geography. This evidence is apparent in declines over time in the absolute value of the estimated coefficients on distance and some other variables related to geography in cross-section regressions for each year from 1975 to 2000. Panel estimates based on a variety of estimation methodologies indicate that the decline in the estimated coefficients on distance and population in the 1990s is statistically significant.

Our results differ from those found in the literature mainly because we estimate a nonlinear version of the gravity model with an additive error term rather than the standard log-linear specification. We prefer the nonlinear specification because it utilizes the information in the observations where bilateral trade is zero. The log-linear specification discards this information, resulting in potentially biased and inconsistent estimates, and is very sensitive to ad hoc methods used in the literature to deal with the "problem" of zero observations. The nonlinear specification has other advantages. The level of the estimated distance coefficients from the nonlinear model is more consistent with theoretical priors than the coefficients from the log-linear model.

In our nonlinear specification of the gravity model, the coefficient estimates on a variety of measures of geography—distance, remoteness, and size—clearly decline over time. Our results, including the panel results based on Tobit estimates and the estimation procedures used by Helpman, Melitz, and Rubinstein (2007) and Silva and Tenreyro (2006), suggest that the declining importance of geography made its mark in the 1990s, which coincides with the apparent acceleration of technological change in the United States and some other countries. We interpret these results as evidence of the diminishing importance of geography, consistent with the phenomenon of globalization.

We conclude with one final observation on empirical gravity models. For years, even decades, the log-linear model has been the workhorse of gravity model estimates. We suspect this is partly because the log-linear model is not computationally demanding. Recent theoretical developments highlight the bias stemming from discarding the zero-valued trade observations. At the same time, expanding computational capacity has made alternatives to the log-linear model feasible to implement. We do not claim that our nonlinear model is the only, or even the preferred, alternative to the log-linear specification. But for the globalization issue addressed in this paper, a nonlinear specification gives very different results than does the conventional log-linear specification, results that are more consistent with theoretical priors on the magnitude of key elasticities, and more consistent with the intuition that globalization has reduced the importance of distance as a restraining influence on international trade.[17]

APPENDIX

Data Sources and Definitions.

Variable	Definition	Source
$TRADE_{ij}$	Sum of country *i*'s imports from country *j* and country *j*'s imports from country *i* (current US$ billions)	IMF, Direction of Trade Statistics database
Y_i (Y_j)	GDP of country *i* (*j*) (current US$ billions)	IMF, World Economic Outlook database
P_i (P_j)	Population of country *i* (*j*) (millions of inhabitants)	IMF, World Economic Outlook database
D_{ij}	Distance between the capital cities of countries *i* and *j* (km)	Fitzpatrick and Modlin (1986)
A_{ij}	Dummy variable taking the value of one if countries *i* and *j* share a common border and zero otherwise	
L_{ij}	Dummy variable taking the value of one if countries *i* and *j* share a common language (English, French, Portuguese, or Spanish) and zero otherwise	Katzner (1986)
F_{ij}	Dummy variable taking the value of one if countries *i* and *j* are members of a common free-trade arrangement (changes over time according to membership) and zero otherwise	

Countries

Algeria
Argentina
Australia
Austria
Bangladesh
Bolivia
Brazil
Cameroon
Canada

[17]There are other instances, however, where nonlinear and log-linear gravity models may give similar results. Coe and Hoffmaister (1999), for example, find that Africa slightly overtrades, based on a nonlinear specification of the gravity model, as does IMF (2002), based on the conventional log-linear specification. See also Subramanian and Tamirisa (2003).

Chile
China
Colombia
Congo, Democratic Republic of
Congo, Republic of
Costa Rica
Côte d'Ivoire
Denmark
Egypt
Ethiopia
Finland
France
Germany
Ghana
Greece
Guatemala
Guyana
Hong Kong SAR
Iceland
India
Indonesia
Iran, I.R. of
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kenya
Korea
Madagascar
Malawi
Malaysia
Mauritius
Mexico
Morocco
Netherlands
New Zealand
Nigeria
Norway
Pakistan
Paraguay
Peru
Philippines
Portugal
Saudi Arabia
Senegal
Singapore
Spain
Sri Lanka
Sweden
Switzerland
Taiwan Province of China
Tanzania
Thailand
Tunisia
Turkey
Uganda
United Kingdom
United States
Uruguay
Venezuela
Zambia
Zimbabwe

REFERENCES

Anderson, J.E., and D. Marcouiller, 2002, "Insecurity and the Pattern of Trade: An Empirical Investigation," *Review of Economics and Statistics*, Vol. 84 (May), pp. 342–352.

Anderson, J.E., and E. van Wincoop, 2003, "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, Vol. 93 (March), pp. 170–192.

———, and E. van Wincoop, 2004, "Trade Costs," *Journal of Economic Literature*, Vol. 42 (September), pp. 691–751.

Berthelon, M., and C. Freund, 2004, "On the Conservation of Distance in International Trade," World Bank Policy Research Working Paper No. WPS 3293 (May).

Boisso, D., and M. Ferrantino, 1997, "Economic Distance, Cultural Distance, and Openness in International Trade: Empirical Puzzles," *Journal of Economic Integration*, Vol. 12 (December), pp. 456–484.

Brun, J.F., C. Carrère, P. Guillaumont, and J. de Melo, 2005, "Has Distance Died? Evidence from a Panel Gravity Model," *World Bank Economic Review*, Vol. 19 (1), pp. 99–120.

Coe, D.T., and A.W. Hoffmaister, 1999, "North-South Trade: Is Africa Unusual?" *Journal of African Economies*, Vol. 8 (2), pp. 228–256.

Deardorff, A.V., 1998, "Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?" in *The Regionalization of the World Economy*, National Bureau of Economic Research Project Report, ed. by J.A. Frankel (Chicago, University of Chicago Press).

Eichengreen, B., and D.A. Irwin, 1998, "The Role of History in Bilateral Trade Flows," in *The Regionalization of the World Economy*, National Bureau of

Economic Research Project Report, ed. by J.A. Frankel (Chicago, University of Chicago Press).

Fitzpatrick, G.L., and M.J. Modlin, 1986, *Direct-Line Distances: International Edition* (Metuchen, New Jersey, Scarecrow Press).

Frankel, J.A., 1997, *Regional Trading Blocs in the World Economic System* (Washington, Institute for International Economics).

———, and A. Rose, 2002, "An Estimate of the Effect of Common Currencies on Trade and Income," *Quarterly Journal of Economics*, Vol. 117 (May), pp. 437–466.

———, and S.J. Wei, 1998, "Regionalization of World Trade and Currencies: Economics and Politics," in *The Regionalization of the World Economy*, National Bureau of Economic Research Project Report, ed. by J.A. Frankel (Chicago, University of Chicago Press).

Freedman, D.A., 1981, "Bootstrapping Regression Models," *Annals of Statistics*, Vol. 9 (November), pp. 1218–1228.

Greene, W.H., 1981, "On the Asymptotic Bias of the Ordinary Least Squares Estimator of the Tobit Model," *Econometrica*, Vol. 49 (March), pp. 505–513.

Grossman, G.M., 1998, "Comment on Deardorff," in *The Regionalization of the World Economy*, National Bureau of Economic Research Project Report, ed. by J.A. Frankel (Chicago, University of Chicago Press).

Harrigan, J., 2003, "Specialization and the Volume of Trade: Do the Data Obey the Laws?" in *Handbook of International Trade*, Blackwell Handbooks in Economics, ed. by E.K. Choi and J. Harrigan (Malden, Massachusetts, Blackwell Publishing).

Heckman, J.J, 1979, "Sample Selection Bias as a Specification Error," *Econometrica*, Vol. 47 (January), pp. 153–162.

Helliwell, J.F, 1998, *How Much Do National Borders Matter?* (Washington, Brookings Institution Press).

Helpman, E., M. Melitz, and Y. Rubinstein, 2007, "Estimating Trade Flows: Trading Partners and Trading Volumes," NBER Working Paper No. 12927, February 2007.

Hummels, D, 1999a, "Have International Transportation Costs Declined?" Available via the Internet: http://ntl.bts.gov/lib/24000/24400/24443/hummels.pdf.

———, 1999b, "Toward a Geography of Trade Costs," GTAP Working Paper No. 17 (West Lafayette, Indiana, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University). Available via the Internet: http://www.gtap.agecon.purdue.edu/resources/download/2010.pdf.

———, 2001, "Time as a Trade Barrier," GTAP Working Paper No. 18 (West Lafayette, Indiana, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University). Available via the Internet: http://www.gtap.agecon.purdue.edu/resources/download/2009.pdf.

International Monetary Fund, 2002, *World Economic Outlook September 2002: Recessions and Recoveries*, World Economic and Financial Surveys (Washington, International Monetary Fund).

———, various issues, *Direction of Trade Statistics Yearbook* (Washington, International Monetary Fund).

———, various issues, *International Financial Statistics* (Washington, International Monetary Fund).

Katzner, K, 1986, *The Languages of the World* (London, Routledge & Kegan Paul).

Leamer, E.E., and J. Levinsohn, 1997, "International Trade Theory: The Evidence," in *Handbook of International Economics*, Vol. 3, ed. by G.M. Grossman and K. Rogoff (New York, Elsevier).

Manning, W.G., and J. Mullahy, 2001, "Estimating Log Models: To Transform or Not to Transform?" *Journal of Health Economics*, Vol. 20 (July), pp. 461–494.

McDonald, J.F., and R.A. Moffitt, 1980, "The Uses of Tobit Analysis," *Review of Economics and Statistics*, Vol. 62 (May), pp. 318–321.

Obstfeld, M., and K. Rogoff, 2000, "The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?" in *NBER Macroeconomics Annual 2000*, ed. by B. Bernanke and K. Rogoff (Cambridge, Massachusetts, MIT Press).

Rauch, J.E., 1999, "Networks vs. Markets in International Trade," *Journal of International Economics*, Vol. 48 (June), pp. 7–35.

Saito, M., 2004, "Armington Elasticities in Intermediate Inputs Trade: A Problem in Using Multilateral Trade Data," *Canadian Journal of Economics*, Vol. 37 (November), pp. 1097–1117.

Silva, J.M.C.S., and S. Tenreyro, 2006, "The Log of Gravity," *Review of Economics and Statistics*, Vol. 88 (August), pp. 641–658.

Soloaga, I., and L.A. Winters, 2001, "Regionalism in the Nineties: What Effect on Trade?" CEPR Working Paper No. 2183 (London, Centre for Economic Policy Research).

Subramanian, A., and N. Tamirisa, 2003, "Is Africa Integrated in the Global Economy?" *IMF Staff Papers*, Vol. 50 (December), pp. 352–372.

Wang, Z.K., and L.A. Winters, 1992, "The Trading Potential of Eastern Europe," *Journal of Economic Integration*, Vol. 7 (Autumn), pp. 113–136.

Wei, S.J., 1996, "Intra-National vs. International Trade: How Stubborn Are Nations in Global Integration?" NBER Working Paper No. 5531 (Cambridge, Massachusetts, National Bureau of Economic Research).