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The Missing Globalization Puzzle

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The Missing Globalization Puzzle

Prepared by David T. Coe, Arvind Subramanian, and Natalia T. Tamirisa, with Rikhil Bhavnani[1]

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Abstract

The failure of declining trade-related costs to be reflected in estimates of the standard gravity model of bilateral trade might be called the "missing globalization puzzle." This puzzle is most apparent in the estimated distance coefficients found in the literature, which show no evidence of declining in absolute value over time. In contrast, we find evidence of globalization, on both cross-section and panel data, reflected in a variety of measures of geography. Our estimation procedure is consistent with recent theoretical developments that emphasize the importance of relative costs for determining bilateral trade patterns. But the main reason our findings differ from previous studies is our nonlinear specification, which has a number of advantages over the standard log-linear specification.

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Authors' e-mail addresses: dcoe@imf.org, asubramanian@imf.org (corresponding author), ntamirisa@imf.org

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I. Introduction

Obstfeld and Rogoff (2001) have drawn attention to six puzzles in international macroeconomics. They argue that the costs of trade—including not just the costs of transportation but also of communications, search, information, and so on—across borders relative to costs within borders have an important role in explaining all these puzzles. In this paper, we focus on another international trade puzzle that relates to the evolution in these costs over time.

Globalization can be characterized, for our purposes, as the rapid increase in international trade spurred by advances in technology that have decreased the costs of trade over time. From the large empirical literature, we know that bilateral patterns of international trade are well explained by the gravity model, which has become the workhorse of international trade in recent years. But while empirical gravity models explain cross-country trading patterns well, they show no evidence that globalization has led to a decrease in the costs of trade over time. Equations estimated on 1970s or 1980s data, or data from even further back, look pretty much the same as those estimated on more recent data. This is particularly true for the estimated coefficients on distance, which are broadly stable. To paraphrase Robert Solow's famous quip about the productivity puzzle, globalization is everywhere but in estimated gravity models.

A stable distance coefficient is surprising since distance is a proxy for all trade-related costs in traditionally estimated gravity models; as these costs have declined over time, so too should the estimated distance coefficients. Numerous possible explanations have been suggested for this puzzling, counterintuitive result, but they are not entirely convincing. We refer to this (negative) result, which has by now been confirmed many times over (see, for example, Frankel, 1997; Leamer and Levinsohn, 1995; and Eichengreen and Irwin, 1998), as the missing globalization puzzle.

Anderson and van Wincoop (2001) have recently argued that most, if not all, empirical analyses based on the gravity model have been based on specifications that are not consistent with the theoretical model: as the title to their paper implies, the empirical gravity models lack *gravitas* in that they have not paid sufficient attention to the theoretical foundations.[2] In Anderson and van Wincoop's model, and in Deardorff's (1998), there are two relative costs that are important for bilateral trade: first, bilateral trading costs relative to the average costs of trading with the rest of the world, and, second, bilateral trading costs relative to the costs of trading with oneself. Anderson and van Wincoop argue that the misspecified models either focus on absolute rather than relative trade costs, or include a "remoteness" variable whose specification is inconsistent with the theoretical model.

[2] Our references to Anderson and van Wincoop (2001) are to the revised version available at www.virginia.edu/~econ/vanwincoopx.htm.

This paper has two objectives. The primary objective is to revisit the missing globalization puzzle. In doing so, and consistent with the theoretical work mentioned above, we broaden the focus beyond simply the distance coefficient to encompass other coefficients related to geography. A secondary objective is to explore the missing globalization puzzle in the context of Anderson and van Wincoop's suggested specification.

We find considerable evidence of globalization. Our estimates of a nonlinear gravity model on both cross-section and on panel data show a clear trend decline in the absolute value of some of the key estimated coefficients related to geography. This decline is particularly pronounced for the distance coefficients, but is also apparent in the estimated coefficients on other measures of geography, including measures of remoteness and country size, where the latter is a proxy for the costs of trading with oneself. In addition, the magnitude of the estimated distance coefficients in our preferred specification is closer to theoretical priors than those found in the literature. These results obtain for the Anderson and van Wincoop (2001) specification as well as for a specification with a remoteness variable similar to that used in previous studies.

The paper is organized as follows. Section II elaborates on the missing globalization puzzle by reviewing both the theoretical and empirical literature on gravity models. Section III outlines the methodology used in the empirical analysis. Section IV presents the empirical results. Section V concludes. Data definitions and sources are presented in the appendix.

II. The Missing Globalization Puzzle

In its simplest form, the gravity model relates bilateral trade between countries during a given time period to the economic mass of the two countries and the distance between them

$$Trade_{ij} = (Y_i Y_j)^{\alpha} D_{ij}^{\beta} \tag{1}$$

where $Trade_{ij}$ is trade between country i and country j, Y is GDP, and D_{ij} is geographic distance between the two countries; time subscripts have been omitted for simplicity. There is an additional term, which we discuss in the next section, that includes an error, a constant, and, perhaps, dummy variables to test for differences in trading patterns for different groups of countries. Trade is expected to be positively related to economic mass ($\alpha > 0$) and negatively related to distance ($\beta < 0$). Most empirical estimates of the gravity model are based on a log-linear transformation of (1), although there are both theoretical and empirical problems with this specification, as discussed in the next section[3]

$$\log Trade_{ij} = \alpha[\log Y_i + \log Y_j] + \beta \log D_{ij} \tag{2}$$

[3] We use the same symbols to represent parameters for the same variables in different specifications.

As is well known, the successful empirical implementation of the gravity model preceded by a number of decades the elaboration of its theoretical foundations.[4] Although distance appears in all *empirical* gravity models, the *theoretical* models relate trade to transport costs, for which distance is a proxy. The relationship between trade costs and distance can be expressed as follows, corresponding to the nonlinear and the log-linear specifications of the gravity model

$$C_{ij} = D_{ij}^{\theta} \quad \text{(3a)}, \qquad \log C_{ij} = \theta \log D_{ij} \quad \text{(3b)}$$

where C_{ij} is trade costs between i and j. The elasticity of trade costs with respect to distance is positive, so $\theta > 0$. With globalization, one would expect to see θ declining over time, as discussed below.

Starting with a theoretical model relating bilateral trade to incomes and trade costs (rather than distance), and then substituting equations (3a) or (3b) for transport costs, one gets the empirical gravity equations (1) or (2) relating trade to distance.[5] The estimated coefficients on distance, β, therefore, implicitly subsume the elasticity of trade costs with respect to distance, θ, along with the elasticity of trade with respect to trade costs. From Deardorff (1998) and Anderson and van Wincoop (2001), the coefficient on distance in a gravity equation is the product of the elasticity of trade costs with respect to distance and (1-ξ), where ξ is the elasticity of substitution between all goods: $\beta = \theta(1-\xi)$. This means that 1-ξ can be interpreted as the elasticity of trade with respect to trade costs. As long as θ is declining over time with globalization, β will also decline.

But 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 over time. We refer to this result as the missing globalization puzzle. Different studies report estimates of distance coefficients that vary between -0.5 and -1.0 or higher, with no tendency for the value to decline over time.

- Frankel (1997, Table 4.2) reports estimates that rise from -0.483 in 1965 to -0.733 in 1992, and Frankel and Rose (2002) obtain an estimate of about -1.1 based on panel estimation for 1970–95;
- Soloaga and Winters (2001) report coefficient estimates of -0.96 in the early 1980s that rise to over -1 in the mid-1990s;
- Eichengreen and Irwin (1998) report estimates ranging from -0.8 to -0.9 for 1949, which decline slightly to about -0.74 for 1964;

[4] See the discussion in Deardorff (1998) and Helliwell (1998).

[5] If equations (3a) and (3b) included fixed costs, substitution into a theoretical gravity equation would be more complex, and not yield the relatively simple empirical specification in (1) or (2). We discuss the implications of fixed and other costs unrelated to distance below.

- Helliwell (1998) reports estimates for intra-OECD trade that are broadly stable at about -0.9 from 1988 to 1992; for global trade that rise from -0.72 in 1988 to -0.82 in 1992; and for trade between Canadian provinces and U.S. states that are relatively stable at about -1.5 in the years from 1988 to 1996; and
- Brun *et al.* (2002) report estimates that increase from -1.2 in 1962 to -1.3 in 1995.

Even allowing for different sample sizes and specifications, the consensus is that the distance coefficient seems not to have declined (in absolute magnitude), and may even have risen, over time.[6]

Can this puzzle of stable or increasing distance coefficients be explained or explained away? Leamer and Levinsohn (1995, pp. 1387–88) clearly see the stability of the distance elasticity as odd enough to warrant explanation: "... 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."

Four types of possible explanations for this puzzle have been proposed: the decline in average costs relative to marginal costs of trade over time; the increased dispersion of economic activity; the changing composition of trade; and the importance of relative rather than absolute costs in determining bilateral trade.

The first explanation is based on the relationship between the distance coefficient in the gravity model, β, and the average and marginal costs of trade. In equations (3a) and (3b), the elasticity of trade costs with respect to distance, θ, is, by definition, the ratio of marginal costs (*MC*) to average costs (*AC*); thus, $\beta = (1\text{-}\xi)\, MC/AC$. Improvements in technology have reduced both average and marginal costs. The empirical question then is whether marginal costs have declined more or less (proportionally) than average costs. If marginal costs have declined more (less) than average costs, θ, and hence the distance coefficient β in the gravity model, should decline (increase).[7]

Unfortunately, the empirical evidence on trade-related costs does not distinguish between marginal and average costs. The evidence can be summarized as follows.

- There have been large declines in *transport costs*, expressed in terms of costs per unit of the volume of trade, over the course of the twentieth century. For example, average ocean freight and port charges per ton of U.S. cargo declined by nearly 75 percent between 1920 and 1990. Average air transport revenue per passenger fell from $0.68 in 1930 to

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[6] An exception is Boisso and Ferrantino (1993) who report declining distance elasticities, but their estimates also yield implausibly high income elasticities, sometimes exceeding 4.

[7] This strict relationship between θ and β need not hold if there are fixed costs (i.e., a constant) in equations (3a) and (3b).

$0.11 in 1990. Further, the worldwide c.i.f. margin as a proportion of the product value of traded goods has declined substantially, from about 12 percent in the 1950s to 5–6 percent in the early 1990s. It appears that these declines mainly occurred in the period before 1980 and that declines in transport costs have subsequently leveled off (Hummels, 1999; IMF, 2002). However, measures of transport costs are not adjusted for factors such as speed, reliability, and quality. Improvements in these factors could mean that the measured declines in transport costs before 1980 may be significantly understated, and that transport costs may have continued to decline after 1980 (Hummels, 2001).

- Other aspects of trade costs more broadly defined to include the *cost of search, communication, and information*, including access to information and the ability to process it, have also declined. For example, the cost of a three-minute telephone call from New York to London declined from $244.65 in 1930 to $3.32 in 1990, and is less than $0.50 today. Declines in other types of trade-related costs appear to have persisted through the last two decades (Loungani *et al.* 2002).

Because the data on transport costs do not indicate whether marginal costs with respect to distance have declined more than average costs, it is not possible to be definitive about how the estimated distance coefficients in gravity models should have evolved. We do, however, present a limit argument below that implies that as transport costs go to zero, the estimated distance coefficients must also go to zero, implying that marginal costs with respect to distance will fall relative to average costs. In our empirical work, we also seek to isolate the marginal cost element of trade-related costs by relating changes in the price of oil, an important component of marginal transport costs, to the evolution in the estimated distance coefficients over time.

The second type of explanation for the puzzle of stable distance coefficients focuses on the dispersion of economic mass. The importance of dispersion is highlighted by Leamer and Levinsohn's (1995, p. 1388) explanation for rising trade (italics ours):

> … the gravity models account for economic size as well as for distance. This model predicts that the smallest amount of world trade occurs when most of the world's GDP originates in one country (e.g., the U.S.). As the U.S. share of world GDP has declined, this implies an increase in the volume of trade relative to world GDP, *even though the effect of distance remains exactly the same*. Indeed the increased trade across the oceans is almost fully explainable by the increase in the economic sizes of Europe and Asia. Thus, dispersion of economic mass is the answer, not a shrinking globe.

That a more uniform distribution of incomes leads to more trade is also implied by the Helpman-Krugman theories of trade (Helpman, 1987; Krugman, 1995). Increased dispersion however, does not help resolve the puzzle for two reasons. The first is that, at least in our sample, there is evidence of a large increase in inequality or greater concentration of economic mass—that is, less dispersion—as measured by two measures of inequality

(Table 1).[8] More importantly, the gravity model, particularly when mass enters multiplicatively in the estimating equation, controls for dispersion, a point noted by Frankel (1997). If the globe is shrinking because trade-related costs are declining, this should be reflected in declining coefficient estimates on distance even with, and after controlling for, greater dispersion of economic mass.

The third type of explanation for the stability over time of the estimated distance coefficients focuses on the changing composition of trade, including the appearance of newly traded products and the shift towards trade in differentiated products. Some products may become tradable as the costs of transport decline over time. If the previously-nontraded goods are not captured in the gravity equation estimated for earlier time periods, perhaps because observations where bilateral trade is zero are excluded in order to estimate a log-linear specification, then the estimated coefficients on distance could remain stable or even increase over time if trade costs for newly traded goods are higher than trade costs for goods traded in both periods.

There may also be products that are truly new in the sense that they did not previously exist. Examples of such new products are personal computers, mobile telephones, and other types of high-tech products. In this case, the estimated distance coefficients would increase over time only if the marginal transport costs for these products are higher than the average marginal cost for the previously-existing traded products.

Rauch (1999) has drawn attention to the fact that transport costs depend upon the type of traded product. In particular, he shows that search costs—an important component of trade costs when products are differentiated—are higher for trade in differentiated products. If the composition of world trade is shifting toward trade in differentiated products, the distance coefficient need not decline over time. It should be noted that arguments about the changing composition of trade do not provide clear priors about the change in the distance coefficient over time because they do not distinguish between marginal and average costs. For example, if search costs have gone up, but their average components have increased more rapidly than the marginal ones, the distance coefficient would still decline over time.

The fourth type of explanation is related to relative rather than absolute trade costs. In Deardorff's (1998) and Anderson and van Wincoop's (2001) theoretical gravity models, bilateral trade is related not to bilateral trade costs alone but to some measure of relative trade costs. In Deardorff (1998), this is measured as the importing country's relative distance from its suppliers compared with all demanding countries' relative distance from that supplier. In Anderson and van Wincoop (2001) this is measured as the bilateral trade costs relative to the average barriers that the partners face with all other trading partners, which they call

[8] The two measures are one-half the square of the coefficient of variation and the mean logarithmic deviation. As Sala-i-Martin (2002) shows, both these measures satisfy certain desirable criteria for an inequality measure.

Table 1. Data 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
Measures of dispersion [1]						
Variation	2.27	1.96	2.63	2.62	3.08	2.91
Mean logarithmic deviation	1.27	1.31	1.36	1.57	1.67	1.57
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	

See appendix for data definitions and sources.

[1] An increase signifies reduced dispersion or greater concentration of economic mass. Variation is calculated as one half of the square of the coefficient of variation of the level of GDP. The mean logarithmic deviation is the difference between the logarithm of mean GDP and the mean of the logarithm of GDP.

"multilateral resistance." In both models, bilateral trade is homogenous of degree zero in relative costs.[9] That is, if bilateral transport costs decline at the same rate as average trade costs of the partners with all countries, bilateral trade remains unaffected.

However, if shipping costs at all distances were proportionately lowered, the homogeneity property in both the Deardorff and Anderson and van Wincoop models also requires a proportional decline in the costs of a country trading with itself. If this does not hold, a country will trade less with itself, implying that its international trade will expand. We would argue that globalization is about the decline in the costs of cross-border trade *relative* to intranational trade, not a general reduction in all trade costs. And this is consistent with the stylized fact that international trade has tended to expand roughly twice as fast as GDP (a proxy for intranational trade) in the last few decades. Indeed, the Obstfeld and Rogoff (2001) explanation for the six puzzles is based on the costs of international trade relative to the costs of intranational trade exceeding unity. Thus, in explaining the impact of a general reduction in transport factors, Deardorff (1998, p. 20) notes that "Of course a country is its own closest neighbor, and therefore purchases of a country from itself also contract. It follows that international trade expands."

It is important to recall that theoretical gravity models imply that a complete elimination of trade costs would render distance irrelevant.[10] In light of this limit result, the explanations discussed above for why the estimated distance coefficients do not decline over time imply a nonmonotonicity or kink in the relationship between trade costs and the estimated geography effect in gravity models: initially, as trade costs—whether average or marginal—decline, the estimated coefficients on distance remain unchanged, or even increase, but in the limit when trade costs are eliminated, the coefficient becomes zero as the effect of geography disappears. Invoking such nonmonotonicity as an explanation for the stability of estimated distance coefficients does not seem very appealing.

III. Equation Specifications

Our empirical work is based on expanded versions of the nonlinear equation (1) estimated on cross-country and panel data for each of the past 25 years. We concentrate on the nonlinear version of the gravity model for two reasons, one theoretical and one empirical. The theoretical reason is that the nonlinear specification implies that trade will go to zero as the size of either country goes to zero, which must be correct, as noted by Deardorff (1998, p. 9). Log-linear specifications do not have this property. The empirical reason is that bilateral

[9] See equation 13 in the revised version of Anderson and van Wincoop (2001) and equation 21 in Deardorff (1998).

[10] In the equations cited in the previous footnote, 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).

trade between a substantial number of countries in our sample is zero—as shown in Table 1, observations where bilateral trade is zero account for almost 12 percent of the total in 1975 and 6 percent in 2000. This fact precludes a log-linear specification if one wants to include all valid observations. For these reasons, we prefer the nonlinear specification on *a priori* grounds.[11]

Nevertheless, for comparison with other studies we also estimate expanded versions of the log-linear equation (2). This requires us to omit the zero observations, which represents a nonrandom screening of the data that may lead to biased or inconsistent estimates.[12] As will be seen below, the log-linear specifications give very different results than the nonlinear specifications.

As noted above, both Deardorff (1998) and Anderson and van Wincoop (2001) emphasize the importance not only of distance (or trade barriers) between two countries, but also of the average trade barriers of the two countries to all their other trading partners. The empirical gravity model literature often includes a remoteness variable, defined in some studies as the weighted distance to all trade partners,[13] as a proxy for this

$$R_i = \Sigma_j w_j D_{ij}, \tag{4}$$

for $i \neq j$, and with $w_j = Y_j / \Sigma_i Y_i$ for all i. A similar variable is defined for country j. The more remote a pair of countries is from the rest of the world, the more they will tend to trade with each other.

Anderson and van Wincoop (2001), however, object that the definitions of the remoteness variable used in the empirical literature are at odds with the theory. Instead, they propose a "multilateral resistance" term that is a function of equilibrium price indices, which are not observable. While Anderson and van Wincoop are able to estimate their model, the

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[11] This is the approach taken in Coe and Hoffmaister (1999) and Subramanian and Tamirisa (forthcoming).

[12] Green (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, i.e., the smaller the share of observations included in the regression the greater the bias.

[13] Our specification of remoteness is similar to that in Frankel and Wei (1998). Polak (1996) was an early attempt to draw attention to the importance of "remoteness," which he measured as the weighted average of bilateral distance from partner countries with weights being the partner countries' share in world exports.

procedure is not straightforward. Fortunately, as they note (p. 17), an alternative estimation method is to replace the multilateral resistance terms with fixed effects. This is the approach we take.

Population of the two countries is often included as an explanatory variable in gravity models. The interpretation is generally that large countries tend to be more self-sufficient, or alternatively, that poorer countries—countries with larger populations for a given level of GDP—trade less than richer countries. For our purposes, however, we prefer to think of population as a measure of country size, and hence as another aspect of geography: for larger countries, the cost of trading with themselves rather than with other countries is relatively low compared with smaller countries (Frankel, 1997). This implies that large countries will tend to trade less than small countries. Over time, trade should become less sensitive to the internal size of a country as the costs of international relative to intranational trade falls, and hence the coefficients on population or land area should decline with globalization.

Finally, we include dummy variables to control for adjacency or common borders, for a common language, and for common membership in a free trade agreement, each of which confers advantages to trade over and above that captured in conventional measures of distance. Trade between countries with these common characteristics will tend to be higher than between more dissimilar countries. The empirical significance of these advantages might also decline with globalization.

Thus, our specification of the Anderson and van Wincoop model is equations (1) or (2) augmented to include population, fixed effects, and dummy variables. The nonlinear version is

$$Trade_{ij} = (Y_iY_j)^{\alpha} D_{ij}^{\beta} (P_iP_j)^{\delta} e^{\mu_{ij}} + \varepsilon_{ij} \text{, with} \tag{5}$$

$$\mu_{ij} = \theta_i + \kappa_j + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} \tag{6}$$

where P is population, ε_{ij} is a well-behaved error term, θ_i is a fixed effect for country i, κ_j is a fixed effect for country j, A_{ij} is a dummy variable equal to 1 if countries i and j share a common border and 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. We expect $\delta < 0$ and $\lambda, \varphi, \sigma > 0$.

While the Anderson and van Wincoop model is our preferred specification, to allow comparison with other studies, we estimate the gravity model with remoteness, as defined in (4), rather than with fixed effects

$$Trade_{ij} = (Y_iY_j)^{\alpha} D_{ij}^{\beta} (P_iP_j)^{\delta} (R_iR_j)^{\gamma} e^{\mu_{ij}} + \varepsilon_{ij} \text{, with} \tag{7}$$

$$\mu_{ij} = \kappa + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} \tag{8}$$

where κ is a constant. The more remote are the two countries from their other trading partners, the more they will trade with each other, so $\gamma > 0$.

We also estimate the more common log-linear specification of the gravity model, although, as noted, this requires that we omit the observations where bilateral trade is zero. As with the nonlinear specifications, equations are estimated with fixed effects following Anderson and van Wincoop (2001), and with remoteness instead of fixed effects

$$\log Trade_{ij} = \alpha \log Y_i Y_j + \beta \log D_{ij} + \delta \log P_i P_j + \theta_i + \kappa_j + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} + \varepsilon_{ij} \quad (9)$$

$$\log Trade_{ij} = \alpha \log Y_i Y_j + \beta \log D_{ij} + \delta \log P_i P_j + \gamma \log R_i R_j + \kappa + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} + \varepsilon_{ij} \quad (10)$$

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—that is, the nonlinear specifications corresponding to equation (1)—include the error in exponential terms rather than additively as in equations (5) and (7). For example, a logarithmic transformation of

$$Trade_{ij} = (Y_i Y_j)^{\alpha} D_{ij}^{\beta} (P_i P_j)^{\delta} e^{\mu_{ij}}, \text{ with} \quad (11)$$

$$\mu_{ij} = \theta_i + \kappa_j + \lambda A_{ij} + \varphi L_{ij} + \sigma F_{ij} + \varepsilon_{ij} \quad (12)$$

would yield equation (9). The additive error term in the nonlinear specification differs from the existing empirical literature that has an additive error term in a log-linear specification. Theoretical gravity models, of course, are nonstochastic and do not point to any priors about the distribution of the error term.

IV. 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

$$Trade_{ij} \equiv M_{ij} + M_{ji}$$

This implies that $Trade_{ij} \equiv Trade_{ji}$. Data sources and definitions are reported in the appendix.

A. Cross-Section Estimates

Estimates of the gravity model on cross section data for selected years during the past 25 years are reported in Table 2. The four specifications reported are: the nonlinear version of the Anderson and van Wincoop specification with (unreported) fixed effects (equation (5)

Table 2. Cross-Section Gravity Model Estimates
(Dependent variable is trade; 73 countries)

	1975	1980	1985	1990	1995	2000
Nonlinear Model						
With fixed effects						
Economic mass	1.02	1.03 *	0.91 *	0.79 *	0.69 *	0.67 *
Distance	-0.44 *	-0.51 *	-0.42 *	-0.33 *	-0.29 *	-0.35 *
Population	-0.39	-0.28 *	-0.09	-0.03	0.13	0.13 *
Adjacency	1.01	0.70 *	0.66 *	0.62 *	0.81 *	0.79 *
Language	0.03	0.08	0.12	0.30	0.28 *	0.18
Free trade agreement	0.89 *	1.05 *	1.56 *	1.65 *	1.40 *	1.13 *
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*
With remoteness						
Economic mass	0.93 *	0.99 *	1.10 *	0.89 *	0.79 *	0.74 *
Distance	-0.53 *	-0.40 *	-0.41 *	-0.32	-0.29 *	-0.32 *
Population	-0.15 *	-0.20 *	-0.22 *	-0.09	0.05	0.11
Remoteness	1.21 *	1.15 *	1.28 *	0.87 *	0.85 *	0.46
Adjacency	0.18	0.45	0.33	0.40	0.29	0.52 *
Language	0.21	0.27	0.05	-0.33	0.15	0.03
Free trade agreement	0.32	0.66	1.28 *	0.78	0.96 *	0.77 *
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*
Log-linear Model						
With fixed effects						
Economic mass	1.40 *	1.22 *	1.03 *	0.97 *	0.88 *	0.84 *
Distance	-0.95 *	-0.96 *	-1.01 *	-0.92 *	-0.98 *	-1.08 *
Population	-0.47 *	-0.18 *	0.10	0.07	0.26 *	0.28 *
Adjacency	0.43	0.37	0.38	0.68 *	0.65 *	0.58 *
Language	1.07 *	0.95 *	0.88 *	0.87 *	0.97 *	0.92 *
Free trade agreement	0.62 *	0.43 *	0.48 *	0.60 *	0.56 *	0.45 *
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*
Adjusted R^2 transformed	*0.52*	*0.70*	*0.69*	*0.64*	*0.60*	*0.58*
With remoteness						
Economic mass	1.35 *	1.33 *	1.31 *	1.22 *	1.18 *	1.18 *
Distance	-1.02 *	-1.01 *	-1.04 *	-0.92 *	-1.00 *	-1.08 *
Population	-0.40 *	-0.33 *	-0.32 *	-0.23 *	-0.14 *	-0.10 *
Remoteness	0.98 *	0.90 *	0.97 *	0.88 *	0.60 *	0.61 *
Adjacency	0.16	0.14	0.19	0.53 *	0.41	0.36
Language	0.98 *	0.84 *	0.64 *	0.75 *	1.01 *	0.85 *
Free trade agreement	0.75 *	0.39 *	0.73 *	0.45 *	0.32 *	0.30 *
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*
Adjusted R^2 transformed	*0.54*	*0.62*	*0.60*	*0.48*	*0.57*	*0.54*

Trade is defined using partner country import data ($T_{ij} = M_{ij} + M_{ji}$). * indicates significantly different from zero at the 5 percent level; in the nonlinear regressions, bias-corrected standard errors have been obtained with bootstrapping techniques. Regressions for 1975 include data for 72 countries. In the log-linear regressions, the exponentials of the predicted values have been used to calculate an adjusted R^2 transformed to be comparable to the adjusted R^2 in the nonlinear model.

above);[14] the nonlinear version of the more conventional specification found in the literature with a remoteness variable, an (unreported) constant, and no fixed effects (equation (7)); the log-linear version of the Anderson and van Wincoop specification with fixed effects (equation (9)); and the log-linear version with remoteness (equation (10)). The nonlinear models are estimated using nonlinear least squares; maximum-likelihood estimation gives similar results. To allow valid hypotheses tests, the nonlinear regressions are bootstrapped to obtain meaningful standard error estimates. Observations where the dependent variable is zero are excluded from the log-linear regressions. The estimation results are generally good, explaining bilateral trade well and with the estimated coefficients almost all of the expected sign and usually significantly different from zero.

The most striking result in Table 2 is the evidence of globalization in the nonlinear specifications. This evidence shows up in the estimated coefficients on distance, remoteness, and population.

- The strongest evidence is the decline in the estimated coefficients on distance in both nonlinear specifications. In the nonlinear specification excluding fixed effects, the distance coefficient falls 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 the nonlinear and the log-linear specifications. In the nonlinear specification, the remoteness coefficient falls by almost 60 percent.
- 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. As argued above, a declining coefficient on population, as a proxy for country size, can be interpreted as evidence of globalization as the costs of international trade decline relative to the cost of intranational trade.

There are a number of other noteworthy features of the estimation results in Table 2:

- There is no evidence of a decline in the estimated coefficients on the adjacency dummy variable.
- In all regressions, there is a trend decline in the estimated coefficients on economic mass. There is some evidence that this decline may be bottoming out in the regressions

[14] In addition to the exclusion of a dummy variable (fixed effect) for one country, given that the regression has a constant term, we had to exclude the fixed effects for the U.S. and China, which are highly correlated (across countries) with income and population, respectively, to avoid multi-collinearity.

for 1995 and 2000. However, the estimated coefficients generally hover around unity, as suggested by the theoretical models.

- The estimated coefficients on the dummy variables for language are generally insignificant in the nonlinear specifications and significant in the log-linear specifications. But in both cases they are broadly stable, as are the estimated coefficients on the free trade agreement dummy.

The estimated coefficients on distance and the other geography variables from cross-country regressions for each year from 1975 to 2000 for the two nonlinear specifications presented in Table 2 are shown in Figure 1. While 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.

B. Robustness

We report in Table 3 a number of alternative specifications of the two nonlinear models to check the robustness of our results. The first two regressions are based on bilateral trade defined as the sum of imports and exports for country *i* rather than as imports from the two countries. A comparison with the first two equations in Table 2 shows that using a different definition of trade makes virtually no difference to our results. To further test the robustness of our results to potential data weaknesses, we also ran regressions excluding bilateral trade among developing countries, where data problems are most acute. The results, which are not reported, were very similar to the regressions reported in Table 2 based on the full sample.

The two regressions at the bottom of Table 3 include the product of land area in the two countries instead of the product of population as a measure of country size. The regressions with fixed effects are similar to those reported in Table 2:[15] the estimated coefficients on distance decline by the same amount; and the coefficients on land area are negative in the earlier years and then become positive but insignificantly different than zero, which is similar to the estimated coefficients on population. In the regression with remoteness, the land area coefficients are negative but stable, while the distance coefficients decline as in Table 2.

C. 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 value 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

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[15] The regression with fixed effects for 1975 is unstable, possibly because of near collinearity between the fixed effects and some of the explanatory variables.

Figure 1. Annual Estimated Coefficients from the Nonlinear Models
(*Trends indicated by straight lines*)

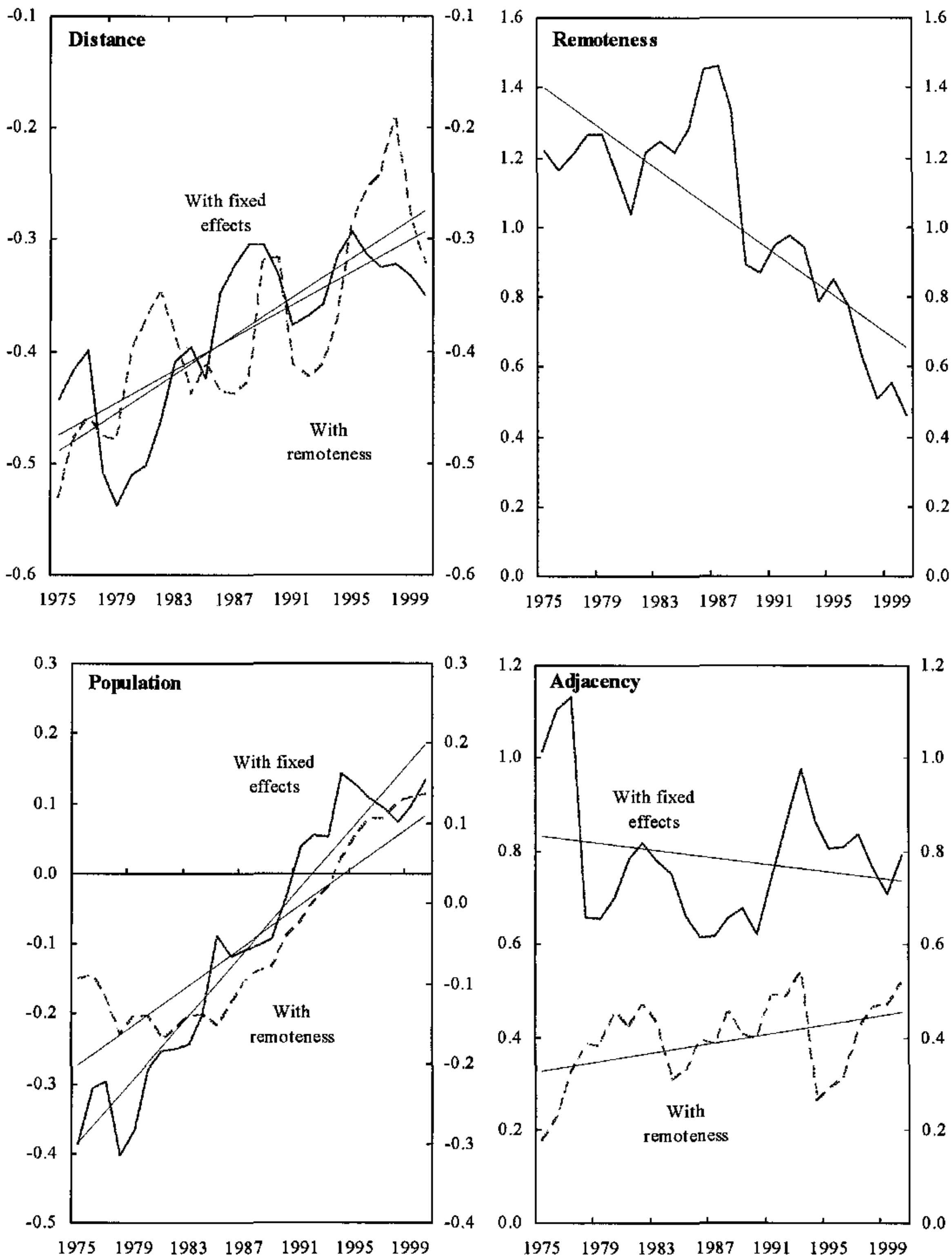

Table 3. Nonlinear Cross-Section Gravity Model Estimates:
Robustness to Alternative Measures of Trade and Economic Size
(Dependent variable is trade; 73 countries)

	1975	1980	1985	1990	1995	2000
Using export data						
With fixed effects						
Economic mass	0.92 *	1.04 *	0.91 *	0.86 *	0.78 *	0.74 *
Distance	-0.44 *	-0.50 *	-0.43 *	-0.33 *	-0.28 *	-0.36 *
Population	-0.23	-0.28 *	-0.07	-0.08	0.07	0.04
Adjacency	1.09 *	0.70 *	0.66 *	0.60 *	0.54 *	0.45 *
Language	-0.10	0.16	0.22	0.40 *	0.41 *	0.38 *
Free trade agreement	0.84 *	1.12 *	1.59 *	1.67 *	1.57 *	1.34 *
Number of observations	*2,292*	*2,487*	*2,556*	*2,591*	*2,607*	*2,612*
Adjusted R^2	*0.96*	*0.96*	*0.98*	*0.97*	*0.98*	*0.99*
With remoteness						
Economic mass	0.99 *	1.00 *	1.13 *	0.93 *	0.82 *	0.78 *
Distance	-0.51 *	-0.38 *	-0.42 *	-0.29	-0.27 *	-0.30
Population	-0.19 *	-0.21 *	-0.25 *	-0.14	-0.02	0.02
Remoteness	1.20 *	1.11 *	1.25 *	0.82 *	0.95	0.64 *
Adjacency	0.22	0.46	0.30	0.35	0.28	0.49
Language	0.24	0.33	0.10	-0.23	0.12	-0.02
Free trade agreement	0.45	0.67	1.32	0.84	1.03	0.87
Number of observations	*2,379*	*2,487*	*2,556*	*2,591*	*2,607*	*2,612*
Adjusted R^2	*0.90*	*0.85*	*0.91*	*0.87*	*0.89*	*0.93*
Using land area						
With fixed effects						
Economic mass	...	1.21 *	0.96 *	0.81 *	0.61 *	0.58 *
Distance	...	-0.51 *	-0.42 *	-0.33 *	-0.29 *	-0.35 *
Land area	...	-0.47 *	-0.15 *	-0.05	0.21	0.22
Adjacency	...	0.70 *	0.66 *	0.62 *	0.81 *	0.79 *
Language	...	0.08	0.12	0.30	0.28	0.18
Free trade agreement	...	1.05 *	1.57 *	1.65 *	1.40 *	1.13 *
Number of observations	...	*2,415*	*2,559*	*2,593*	*2,609*	*2,613*
Adjusted R^2	...	*0.96*	*0.98*	*0.96*	*0.97*	*0.98*
With remoteness						
Economic mass	0.94 *	0.98 *	1.09 *	0.97 *	0.92 *	0.84 *
Distance	-0.63 *	-0.50 *	-0.53 *	-0.28 *	-0.26 *	-0.34 *
Land area	-0.14 *	-0.14 *	-0.20 *	-0.19 *	-0.15 *	-0.13 *
Remoteness	1.66 *	1.56 *	1.80 *	1.64 *	1.89 *	1.34 *
Adjacency	0.23	0.55 *	0.49 *	0.49 *	0.30 *	0.64 *
Language	0.47	0.53 *	0.45 *	0.20	0.43 *	0.21
Free trade agreement	0.06	0.43	0.92 *	0.98 *	1.20 *	0.64 *
Number of observations	*2,342*	*2,415*	*2,559*	*2,593*	*2,609*	*2,613*
Adjusted R^2	*0.89*	*0.87*	*0.94*	*0.91*	*0.90*	*0.91*

In the first two regressions, trade is defined as $T_{ij} = M_{ij} + X_{ij}$. * indicates significantly different from zero at the 5 percent level; in the nonlinear regressions, bias-corrected standard errors have been obtained with bootstrapping techniques. Regressions for 1975 include data for 72 countries.

goods and the share of shipping costs in the total price of a traded product, suggests a value of only -0.03, although he notes that an elasticity of substitution higher than unity would raise this estimate somewhat.[16] Indeed, 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*(1-2)) to -0.6, which is consistent with our estimates.[17]

Grossman's 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 much more consistent with theoretical priors than are results from the log-linear specification or from the literature.

As noted above, the price of oil is an important component of marginal transportation costs, and hence of trade costs. This suggests that the absolute values of the estimated distance coefficients from the yearly regressions shown in Figure 1 should be positively correlated over time with the price of oil. For the nonlinear model with fixed effects, this correlation is apparent in the top panel of Figure 2, which plots the absolute value of the estimated distance coefficients along with the price of oil. A simple regression from 1975–2000 indicates that the correlation is indeed positive and statistically significant.[18] This means that the estimated distance coefficients are larger in absolute value—more negative—during years when oil prices are high, suggesting that the estimated distance coefficients are indeed capturing movements in trade costs. By contrast, there is not a significant correlation between oil prices and the estimated distance coefficients from the log-linear regressions, as shown in the bottom panel of Figure 2.

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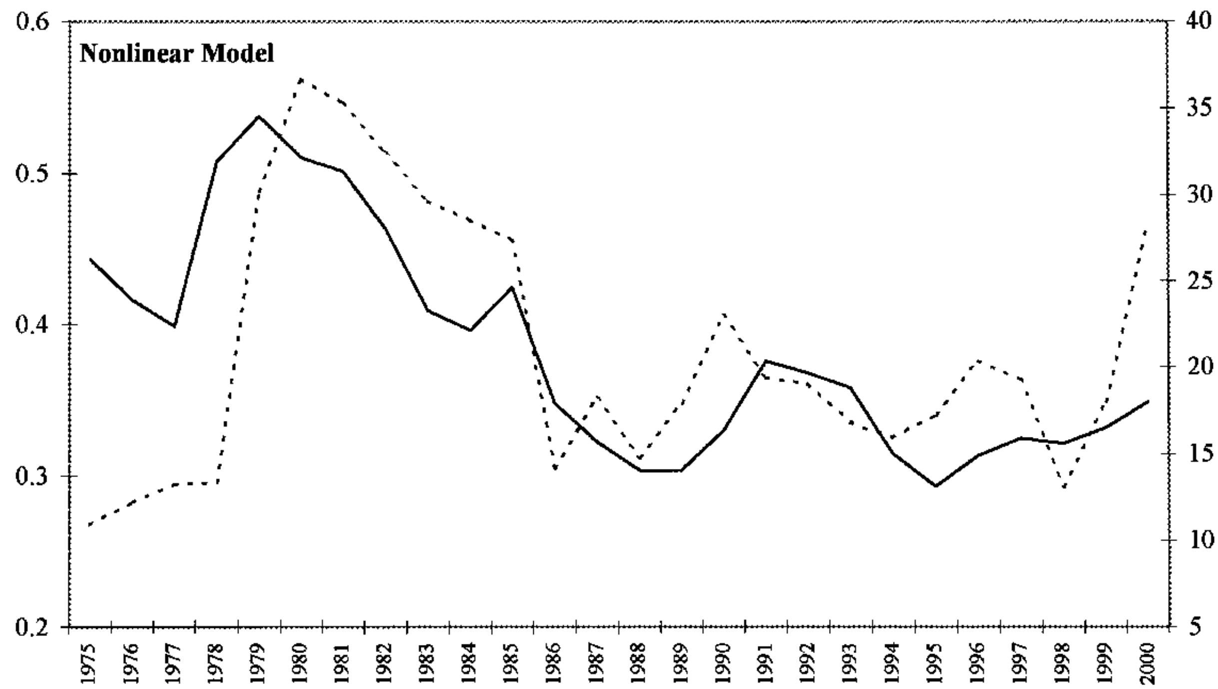
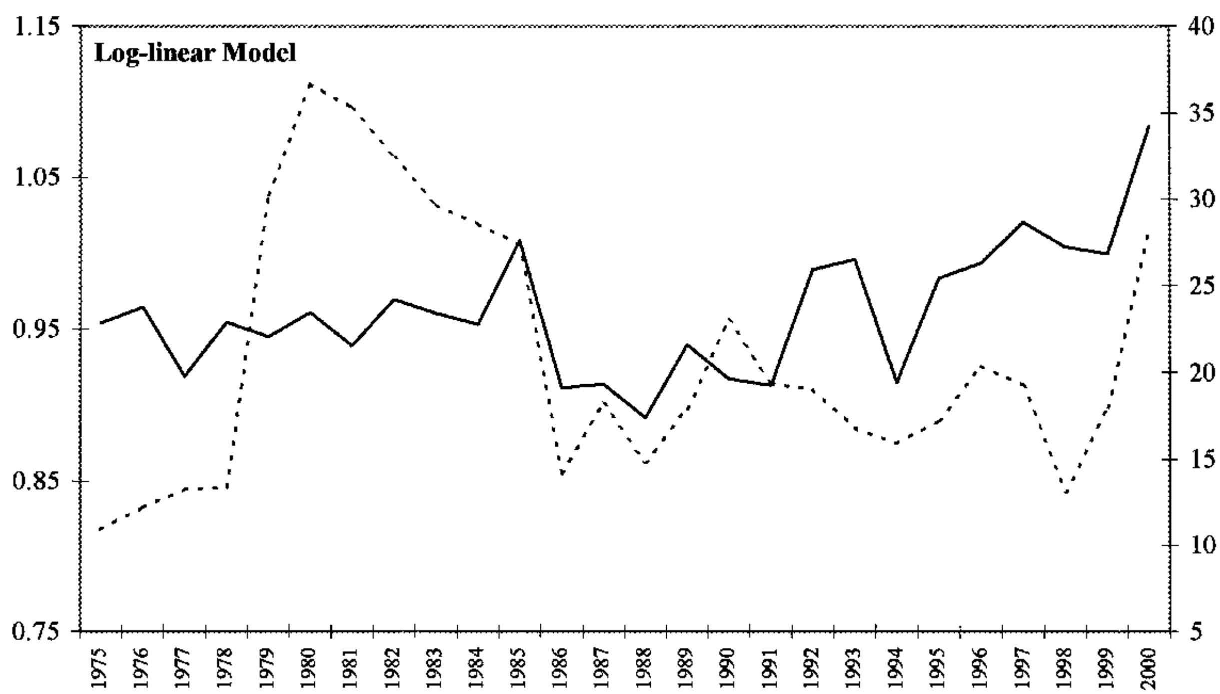
[16] Grossman's Cobb-Douglas assumption and the implied elasticity of substitution between home and foreign goods of 1 is problematic as it would suggest a distance elasticity of zero.

[17] The relevant elasticity of substitution for this calculation is the elasticity between any pair of goods, whether domestically-produced or imported. To the best of 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 (2001) suggest a consensus estimate of the elasticity of substitution between domestic and imported goods of 5 to 6; and Saito (2001) estimates an elasticity of substitution among imports from different OECD countries of about 0.9.

[18] The estimated coefficients on oil prices are significant whether oil prices are entered in logarithms or not, and with or without lags.

Figure 2. Estimated Distance Coefficients and the Price of Oil
(Absolute value of distance coefficients, solid lines, left scale; average oil price, U.S. dollars per barrel, dashed lines, right scale)





D. Nonlinear versus Log-Linear Specifications

The nonlinear models do a much better job of explaining bilateral trade than do the log-linear models, with adjusted R^2s of about 0.9 or higher compared with adjusted R^2s of 0.5–0.7 in the log-linear regressions. (For the log-linear regressions in Table 2, we have taken the exponential of the predicted values to calculate an adjusted R^2 transformed to be comparable to the R^2s for the nonlinear regressions.) The better fit is even more impressive given the higher variance in the raw data used in the nonlinear regressions compared with the logarithmic data used in the log-linear regressions (see Table 1). In addition, the estimated distance coefficients in the nonlinear regressions are considerably smaller, and more consistent with theoretical priors, than in the log-linear regressions.

Why are the nonlinear regressions so different than the log-linear regressions common in the literature? One reason noted above is that the nonlinear regressions include all observations whereas the log-linear regressions exclude observations where bilateral trade is zero. If the zero observations are excluded from the nonlinear regressions, the results are similar to those reported in Table 2. This implies that the nonlinear specification does a very good job of explaining the "zero" observations, either because the nonlinear specification is superior, or because the zero observations are, from the point of view of the regression, statistically similar to other low-value observations.

Unlike the nonlinear regressions, the log-linear regressions are very sensitive to the inclusion of low or near-zero values of bilateral trades. The minimum value of bilateral trade in our dataset is, in fact, quite small at about \$20, which is not too different from zero.[19] 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.[20] If the log-linear regressions with remoteness are run on this expanded dataset, the adjusted R^2 for the regression for 2000 falls from 0.78 to 0.41, which is less than half the adjusted R^2 for the nonlinear regression on the same data; 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 non-zero value of bilateral trade. These experiments, which are similar to the way

[19] In 2000, for example, trade between Algeria and Malawi and between Algeria and Guyana was about \$20, while trade between Bangladesh and the Republic of Congo, between Bolivia and Madagascar, and between Ghana and Paraguay was zero.

[20] This corresponds to a value of the logarithm of bilateral trade measured in billions of dollars that is about 6 log points below the minimums of -14 to -18 reported in Table 1.

zero observations are handled in some gravity model studies,[21] suggest that the bias introduced by excluding the zero observations may be very significant in the log-linear specification.

A second reason for the different results is the different error specifications, as discussed in Section III. When both the nonlinear and the log-linear models are estimated on the same dataset excluding all zero observations, the nonlinear specification is clearly superior, with adjusted R^2s of 0.9 or above compared with adjusted R^2s of 0.5–0.7 in the log-linear regressions shown in Table 2. The difference does not reflect the estimation procedures since either nonlinear or ordinary least squares estimation of the log-linear model yields identical results. This implies that the different error specifications are important, and that the additive specification in our nonlinear model is more consistent with the data than is the additive specification in the log-linear model.

E. Panel Estimates

Given our interest in changes in the estimated coefficients over time, we also estimate the model on a panel dataset created by pooling the annual data used for the cross-section regressions. Ideally, panel estimation would require bilateral trade and GDP to be measured in real terms, which is problematic since bilateral trade deflators are not available. Following Coe and Hoffmaister (1999), we include (unreported) time effects to capture the effects of changes in prices and exchange rates over time.

Panel estimates of the nonlinear specification with remoteness are reported in Table 4.[22] The first regression is the same specification as in the annual cross-section regressions in Table 2. The R^2 is comparable to the cross-section regressions and the estimated coefficients are similar to the average of the annual estimates in Table 2. This suggests that pooling the data is valid and that the time dummies adequately compensate for the lack of the proper deflators. In the second regression, each of the key variables is interacted with a linear trend. These interacted variables are significantly different than zero, and their signs imply that the absolute value of the estimated coefficients on distance, population, and remoteness decline. As in the cross-section regressions, the coefficient on economic mass also declines, while the adjacency coefficient rises. Imposing a monotonic, linear trend may be an unwarranted constraint on the data, and has the uncomfortable implication that the estimated coefficients eventually reverse sign or, in the case of adjacency, increase without limit.

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[21] See, for example, Anderson and Marcouiller (2002) and Wang and Winters (1992).

[22] The similarity of the cross-section results in the specification with fixed effects compared with the specification with remoteness but no fixed effects suggests that the panel results with fixed effects would be similar to the results reported in Table 4.

Table 4. Nonlinear Panel Gravity Model Estimates
(Dependent variable is trade; 73 countries, 1975 –2000)

	Basic Model	Linear Trend	Five-Year Shifts	Ten-Year Shifts
Economic mass	0.80 *	1.07 *	1.03 *	1.03 *
Economic mas *x* trend		-0.01 *		
Economic mas *x* D(80-84)			-0.05	
x D(85-89)			-0.09	
x D(90-94)			-0.23	
x D(95-00)			-0.27 *	
x D(80-89)				-0.08
x D(90-00)				-0.26 *
Distance	-0.38 *	-0.45 *	-0.50 *	-0.50 *
Distance *x* trend		0.004 *		
Distance *x* D(80-84)			0.08 *	
x D(85-89)			0.09	
x D(90-94)			0.17	
x D(95-00)			0.15 *	
x D(80-89)				0.09
x D(90-00)				0.16 *
Population	-0.02 *	-0.32 *	-0.25 *	-0.25 *
Population *x* trend		0.02 *		
Population *x* D(80-84)			0.04	
x D(85-89)			0.12	
x D(90-94)			0.25 *	
x D(95-00)			0.33 *	
x D(80-89)				0.09 *
x D(90-00)				0.32 *
Remoteness	0.78 *	1.17 *	1.39 *	1.40 *
Remoteness *x* trend		-0.02 *		
Remoteness *x* D(80-84)			-0.34 *	
x D(85-89)			-0.48 *	
x D(90-94)			-0.66 *	
x D(95-00)			-0.70 *	
x D(80-89)				-0.43 *
x D(90-00)				-0.70 *
Adjacency	0.53 *	0.23	0.40	0.40 *
Adjacency *x* trend		0.01 *		
Adjacency *x* D(80-84)			0.03	
x D(85-89)			-0.01	
x D(90-94)			-0.01	
x D(95-00)			0.15	
x D(80-89)				-0.004
x D(90-00)				0.10
Language	-0.002	0.02	0.04	0.03
Free trade agreement	0.55 *	0.58 *	0.65 *	0.66 *
Number of observations	*66,159*	*66,159*	*66,159*	*66,159*
Adjusted R^2	*0.88*	*0.89*	*0.89*	*0.89*

Trade is defined using partner country import data ($T_{ij} = M_{ij} + M_{ji}$). All regressions include unreported dummies. * indicates significantly different from zero at the 5 percent level; bias-corrected standard errors have been obtained with bootstrapping techniques. For 1975–79 the panel includes data for 72 countries. The trend is equal to 1 in 1975, 2 in 1976, ..., and 21 in 2000. Shift dummies such as D(80-84) are equal to 1 1980–84 and zero otherwise.

The final two regressions in Table 4 simply allow the estimated coefficients to shift at five-year and, in the final equation, at ten-year intervals. These results are consistent with, and reinforce the cross-section results presented above. Except for adjacency, there is a clear and significant decline in the absolute value of the estimated coefficients on the variables related to geography. The decline in the remoteness coefficient is monotonic, while the decline in the distance coefficient is most pronounced and significant after 1990. As in the annual regressions, the estimated coefficient on population becomes positive after 1990.

V. Conclusion

We refer to the failure of declining trade-related costs—an important aspect of globalization—to be reflected in estimates of the standard gravity model of bilateral trade as the "missing globalization" puzzle. This puzzle is most apparent in the estimated distance coefficients found in the literature, which show no evidence of declining in absolute value over time. If anything, the consensus from the literature is that this coefficient has been constant or even increasing over time. Possible explanations of this puzzling result are, in our view, unconvincing.

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 the cross-section regressions done for each year from 1975 to 2000, and in panel estimates over the same period.

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 version. We prefer the nonlinear specification for a number of reasons:

- The nonlinear model does a much better job of explaining the data, even though the variance of the raw data is much higher than of the corresponding logarithmic data.

- The nonlinear specification utilizes the information in the observations where bilateral trade is zero. The log-linear specification discards this information, which may lead to biased or inconsistent parameter estimates.

- 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.

- The estimated annual distance coefficients from the nonlinear model are correlated over time with the price of oil, suggesting that the cyclical and trend changes over time are indeed related to changes in the marginal costs of trade and transportation. The distance coefficients from the log-linear model, on the other hand, are relatively stable and uncorrelated with oil prices.

We believe that the nonlinear specification of the gravity model is superior to the log-linear specification on both theoretical and empirical grounds. For the globalization issue addressed in this paper, a nonlinear specification gives very different results than the conventional log-linear specification. There are other issues, however, where nonlinear and log-linear gravity models give similar results.[23] This is obviously a fruitful area for further research.

In our nonlinear specification of the gravity model, the coefficient estimates on a variety of measures of geography—distance, remoteness, and size, as proxied by either population or land mass—clearly decline over time. Our results suggest that the declining importance of geography made its mark in the 1990s, especially in the latter half, 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.

[23] 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 (forthcoming).

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).
	Land area (thousands of square kilometers).	World Bank, World Development Indicators database.
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
Chile
China
Colombia
Congo, Democratic Republic of
Congo, Republic of
Costa Rica
Cote D'Ivoire
Denmark
Egypt
Ethiopia
Finland
France
Germany
Ghana
Greece
Guatemala
Guyana
Hong Kong SAR
Iceland
India
Indonesia
Iran
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

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