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Infrastructure, Geographical Disadvantage, Transport Costs, and Trade

Nuno Limão and Anthony J. Venables

The authors use different data sets to investigate the dependence of transport costs on geography and infrastructure. Infrastructure is an important determinant of transport costs, especially for landlocked countries. Analysis of bilateral trade data confirms the importance of infrastructure and gives an estimate of the elasticity of trade flows with respect to the trade cost factor of around –3. A deterioration of infrastructure from the median to the 75th percentile raises transport costs by 12 percentage points and reduces trade volumes by 28 percent. Analysis of African trade flows indicates that their relatively low level is largely due to poor infrastructure.

The real costs of trade—the transport and other costs of doing business internationally—are important determinants of a country's ability to participate fully in the world economy. Remoteness and poor transport and communications infrastructure isolate countries, inhibiting their participation in global production networks.[1] For example, in 1995 landlocked countries on average had an import share in gross domestic product (GDP) of 11 percent, compared with 28 percent for coastal economies. Eight of the top 15 nonprimary export performers for 1965–90 are island countries, and none is landlocked (World Bank 1998).[2] As liberalization continues to reduce artificial trade barriers, the effective rate of protection provided by transport costs is now, in many cases, considerably higher than that provided by tariffs.[3] To bring countries further into

Nuno Limão is with Department of Economics at Columbia University, and Anthony J. Venables is with the Department of Economics at the London School of Economics and the Center for Economic Policy Research. Anthony J. Venables's e-mail is *a.j.venables@lse.ac.uk* Nuno Limão's e-mail address is *ngl4@columbia.edu*. Most of the work on this project was undertaken while Anthony J. Venables was at the World Bank. The authors thank David Hummels, Steve Redding, and anonymous referees for helpful comments.

1. Increasing trade in components and the geographical fragmentation of some production processes make transport costs even more important. See Feenstra (1998) and the references quoted therein for evidence of the increase in the importance of intermediate goods trade. Radelet and Sachs (1998) show how sensitive value added is to transport costs in a vertically fragmented activity.

2. Export performance corresponds to growth in exports of nonprimary manufactured products in 1965–90 (Radelet and Sachs 1998, table 1).

3. See Finger and Yeats (1976) for U.S. post–Kennedy round data on nominal and effective rates of protection afforded by tariffs and transport costs. See Hummels (1998b) for recent data on nominal rates for Argentina, Brazil, New Zealand, and the United States.

the trading system, it is important to understand both the determinants of transport costs and the magnitude of the barriers to trade that they create.

Here we study the determinants of transport costs and show how they depend both on countries' geography and on their level of infrastructure. The importance of geography has been established by Hummels (1998b) as well as by Moneta (1959).[4] We focus on the distance between countries, whether they share a common border, whether they are landlocked, and whether they are islands. The infrastructure measures relate to the quality of transport and communications infrastructure. Although the importance of infrastructure for transport costs is well established in regional and transport economics, the few empirical studies of international transport costs often neglect this and focus on geographical and product characteristics.[5] We show that infrastructure is quantitatively important in determining transport costs, a finding with important policy implications for investment in infrastructure. Poor infrastructure accounts for 40 percent of predicted transport costs for coastal countries and up to 60 percent for landlocked countries. An improvement in own and transit countries' infrastructure from the 25th percentile to the 75th percentile overcomes more than half of the disadvantage associated with being landlocked.

Our research uses different sources of transport cost data. The first is shipping company quotes for the cost of transporting a standard container from Baltimore, Maryland, in the United States, to selected destinations. The advantages of this measure are that it is the true cost of transporting a homogeneous good and that it gives both the city of landfall and the final destination city. This enables us to compare the transport costs of land and sea legs of a journey, finding that the former is around seven times more costly per unit distance. The disadvantage of this data set is that it is not clear how the experience of Baltimore generalizes, because charges are affected by particular routes, frequencies, and opportunities for backhauling and exploiting monopoly power. Our second data set uses a cross section of the ratio of carriage, insurance, and freight (CIF) to free on board (FOB) values that the International Monetary Fund (IMF) reports for bilateral trade between countries. These are representative insofar as they cover the entire imports of each reporting country. However, the measure is an aggregate over all commodity types imported, and there are some questions, which we address, regarding the quality of the data.

In addition to the determinants of transport costs, we want to know the extent to which transport costs choke off trade. To do this we undertake a gravity modeling exercise, incorporating the same geographical and infrastructure measures that we use in estimating trade costs. This analysis strongly confirms the

4. Hummels (1998b) has undertaken a thorough study of the implications of geography for freight rates on disaggregated commodity imports of New Zealand, the United States, and five Latin American countries.

5. An exception to this is Radelet and Sachs (1998), where port quality is entered as an explanatory variable for transport costs.

importance of these variables in determining trade and enables us to compute estimates of the elasticity of trade flows with respect to transport costs. We find that this elasticity is large, with a 10-percentage-point increase in transport costs typically reducing trade volumes by approximately 20 percent.

Taken together, our approaches provide a rather consistent picture of the determinants of transport costs, in particular the importance of infrastructure in source and destination countries and in any transit countries used by landlocked economies. We draw out the implications of our findings by looking in some detail at trade and transport costs in Sub-Saharan Africa. Our measures indicate that many of these economies have extremely high transport costs. We show how taking infrastructure into account explains part of the relative trade performance of these countries.

In section I we discuss the determinants of transport costs and present estimates for the transport cost equation using the shipping data and the CIF/FOB data. In section II we present the gravity results. In section III we compare and contrast the results from the transport cost and gravity analyses and derive an estimate of the elasticity of trade flows with respect to transport costs. We show that improvements in the infrastructure of landlocked countries and their transit countries can dramatically increase trade flows. We analyze trade and transport costs in Sub-Saharan Africa in section IV, finding that infrastructure accounts for much of Africa's poor performance. Section V concludes and summarizes our main quantitative findings.

I. Transport Costs

The Determinants of Transport Costs

Let T_{ij} denote the unit cost of shipping a particular good from country i to country j. We suppose that it is determined by

$$T_{ij} = T(x_{ij}, X_i, X_j, \mu_{ij}), \tag{1}$$

where x_{ij} is a vector of characteristics relating to the journey between i and j, X_i is a vector of characteristics of country i, X_j is a vector of characteristics of country j, and μ_{ij} represents all unobservable variables.

What are the relevant observable characteristics of countries and the journeys between them? For the journey, we use two types of measures, both standard in the literature. The first is whether the countries share a common border, and the second is the shortest direct distance between the countries. The importance of distance for transport costs is obvious, but why should sharing a border reduce transport costs after controlling for distance? First, neighboring countries typically have more integrated transport networks that reduce the number of transshipments, for example, from rail to road or across different types of rail gauge. Second, neighboring countries are more likely to have transit and customs agreements that reduce transit times and translate into lower shipping and insurance costs. Finally, the higher volume of trade between neighboring countries dramatically increases the possibilities for backhauling, allowing the fixed costs to be shared over two trips.

For country characteristics, we focus on geographical and infrastructure measures. The main geographical measures are simply whether the country is landlocked and whether it is an island. The infrastructure measure (*inf*) we use is designed to measure the costs of travel in and through a country. It is constructed as an average of the density of the road network, the paved road network, the rail network, and the number of telephone main lines per person. In our regressions, we always work with an inverse measure of this index; so an *increase* in the variable *inf* is expected to be associated with an *increase* in the costs of transport. Details on the construction of this and other variables are given in the appendix.

Shipping from Baltimore

Our first results are based on the costs of shipping a standard 40-foot container from Baltimore to different destinations around the world. A firm that handles forwarding for the World Bank provided the data, which cover 64 destination cities, 35 of which are in landlocked countries (see appendix tables A-2, A-4, and A-5). This source of data has two major advantages. One is that journeys can be broken down into component parts—the data gives the landfall city for each journey as well as the final destination city—allowing separate estimation of the effect of land and sea distance. The other is that the good shipped is homogeneous, avoiding compositional problems that can occur in aggregate data.[6]

We estimate a linear version of equation 1 both for the entire journey and for the journey divided into the sea journey (to the port) and the land journey (from the port). More specifically, we estimate:

$$T_{ij} = \alpha + \beta' x_{ij} + \gamma' X_i + \delta \ni' X_j + \nu_{ij}, \quad (2)$$

where i corresponds to Baltimore and j represents the destination city. The error term ν_{ij} is assumed to be independent of the explanatory variables and normally distributed.

The most appropriate functional form is not clear a priori. On one hand, we are adding over the different legs of the trip. That is, the cost of going through the infrastructure of the importer and the exporter and the cost of shipping between them suggests a linear form. On the other hand, it is possible that there are interactions among the cost variables that would make a nonlinear form more suitable. The simplest example is that an increase in land distance should increase the cost of going through a given infrastructure. For this reason, we also experi-

6. UNCTAD (1995, p. 58) presents similar data for a sample of four coastal countries and nine landlocked countries in Sub-Saharan Africa. Livingstone (1986) uses quotes made by regular shippers to the Crown agents from the United Kingdom to eight African countries. The small size of the sample in both studies does not allow for a systematic examination of the determinants of transport costs.

mented with some nonlinear forms, but they were rejected by the data.[7] Therefore, table 1 presents the ordinary least squares (OLS) estimation results of the linear form given by equation 2.

The first two columns in table 1 give results excluding the infrastructure variables. There are three main conclusions. First, being landlocked raises costs by \$3,450—compared with a mean cost for nonlandlocked countries of \$4,620. Second, breaking the journey into an overland component and a sea component (the second column in table 1) considerably improves the fit of the equation. It also gives a much larger coefficient for the overland portion of the trip compared with the sea distance. An extra 1,000 km by sea adds \$190, whereas a similar increase in land distance adds \$1,380. When this value is compared with the \$380 per 1,000 km predicted by total straight-line distance (the first column), it becomes clear that using the latter measure leads to a large underestimate of the impact of overland distance on transport costs. Third, the additional transport cost from being landlocked is not fully explained by the extra overland distance that must be overcome to reach the sea. Although the final city destination for landlocked countries is on average four times further from the sea than the final city destination for coastal countries in this sample, the landlocked dummy remains significant after controlling for land distance. There are several possible reasons for this, arising from border delays or transport coordination problems, uncertainty and delays creating higher insurance costs, and direct charges that may be made by the transit country.[8]

The third and fourth columns in table 1 introduce our measures of the inverse infrastructure of the destination (*inf*) and, for landlocked countries, the transit country (*inftran*) for the smaller sample covered by these data.[9] The signs of these are as expected, inferior infrastructures leading to higher transport costs. We can also ask what proportion of the predicted value is explained by infrastructure versus distance. For coastal economies, own infrastructure explains 40 percent of the predicted cost; for landlocked countries, own infrastructure explains 36 percent and transit infrastructure 24 percent of the cost.

The final specification (the fourth column) breaks distance into the overland and sea components. The coefficients on these distance variables are very similar to those in the full sample (the second column). Splitting the distance variable makes the coefficient for transit infrastructure smaller and insignificant because of the variable's high positive correlation with land distance. Moreover, transit and own infrastructure are also highly correlated. This multicollinearity

7. This is true even when quadratic distance terms are added to capture any nonlinearity. These terms are insignificant, further justifying the use of the linear land and sea distance measures. We also estimated equation 2 including the per capita income of the destination country, because low-income countries might have high transport costs for a variety of reasons other than infrastructure. It was not significant.

8. For example, Kenya charges a transit goods license for road transit of \$200 (per entry or 30 days) and tolls on trucks (UNCTAD 1997, p. 11).

9. The landlocked dummy is not included because of its multicollinearity with transit infrastructure.

TABLE 1. The Cost of Shipping a 40-Foot Container from Baltimore, 1990

Variable	1	2	3	4
Infrastructure (*inf*[a])			1.31**	1.56***
			(2.51)	(2.92)
Infrastructure of transit country (*inftran*[a])			1.34**	0.67
			(1.93)	(0.88)
Landlocked country dummy (*ldldummy*[b])	3.45***	2.17***		
	(4.75)	(2.94)		
Distance between trading partners	0.38**		0.29*	
	(2.60)		(1.84)	
Sea distance (*distsea*)		0.19**		0.18*
		(2.12)		(1.74)
Land distance (*distland*)		1.38***		1.49*
		(4.66)		(1.77)
Constant	1.10	2.06*	0.11	–0.10
	(0.95)	(1.85)	(0.093)	(–0.07)
Sample size	64	64	47	47
R^2	0.32	0.47	0.38	0.43
F-test (*p*-values)				
inf, *inftran*				0.00
inftran, distland				0.03

*Significant at the 10 percent level.
**Significant at the 5 percent level.
***Significant at the 1 percent level.
Note: The dependent variable is transport cost, T_{ij}, in thousands of U.S. dollars. The sample used in specifications 3 and 4 is reduced to the countries for which the infrastructure variables are also available. For specifications 1 and 3, the standard errors were adjusted to correct for heteroskedasticity. *t*-statistics are in parentheses. The *F*-tests are for the pairs of variables indicated; the *p*-values show the level at which the null of no joint significance is rejected. See table A-2 for the countries included in the sample.
[a]Values for the infrastructure variables are averages for 1990–95 (the latest year available).
[b]*ldldummy* = 1 if the country has no access to the sea, 0 otherwise.
Source: Authors' calculations.

poses problems for identifying the separate effects of the two variables. However, the tests of significance at the bottom of table 1 confirm the importance of the transit variable when considered jointly with *either* own infrastructure *or* land distance. To reemphasize the relative importance of infrastructure, an improvement of *inf* from the 75th percentile to the median is equivalent to a distance reduction of 3,466 sea km or 419 land km.[10]

10. For 20 landlocked countries in the sample, we have both the costs of shipping to the port and the full cost of shipping to the landlocked destination (for example, the cost of shipping from Baltimore to Durban and that from Baltimore to Harare via Durban). This enables us to look at the determinants of the incremental costs associated with the final stage of the journey. Final destination infrastructure is significant and positive, although incremental distance and port infrastructure are not. This is due both to the small number of observations and to details that become apparent on inspection of the data. For example, shipping from Baltimore to Durban costs $2,500: shipping the 1,600 km further to Lusaka costs an additional $2,500, whereas the 347 km from Durban to Maseru (Lesotho) costs an additional $7,500. This points to the importance of details of geography, market structure, and trade volumes, in addition to the broader picture painted by the econometrics.

CIF/FOB *Measures*

Our second set of experiments is based on the CIF/FOB ratio as derived from the IMF's *Direction of Trade Statistics* (IMF various years). Importing countries report the value of imports from partner countries, inclusive of CIF, and exporting countries report their value FOB, which measures the cost of the imports and all charges incurred in placing the merchandise aboard a carrier in the exporting port. Denoting the FOB price of goods shipped from i to j by p_{ij}, we define t_{ij}, the ad valorem transport cost factor, as

$$t_{ij} \equiv cif_{ij} / fob_{ij} = (p_{ij} + T_{ij}) / p_{ij} = t(x_{ij}, X_i, X_j, \tilde{\mu}_{ij}) \tag{3}$$

where the determinants of T_{ij} are given in equation 1.

The ratio CIF/FOB provides the measure of transport costs on trade between each pair of countries. In theory, the FOB and CIF prices are border prices, and thus it would seem that own and trading partner infrastructures as defined here should not affect these rates. There are three reasons why they are indeed relevant. First, road, rail, and telephone infrastructures are likely highly correlated with port infrastructure (for which we have no data) and the latter would be important even if the prices were pure border prices. Second, the insurance component reflects the total time in transit, that is, from door to door, not just border to border; total transit time is likely to be a function of own and partner infrastructure. Finally, according to UN experts on customs data, the FOB and CIF figures rarely measure actual border prices, instead measuring the prices at the initial point of departure and final destination, respectively.[11] Thus, own and partner infrastructure should be included in the estimation.

Assuming that t can be approximated by a log linear function up to some measurement error, we can write the observed transport cost factors t_{ij} :

$$\ln t_{ij} = \tilde{\alpha} + \tilde{\beta} x_{ij} + \tilde{\gamma}' \ln X_i + \tilde{\delta}' \ln X_j + \omega_j \tag{4}$$

where the tildes distinguish this set of parameters from those in equation 2. The final term, ω_j, contains unobserved variables, which we assume are uncorrelated with the explanatory variables, and random measurement error. As in the previous section, functional form is to a large degree an empirical question. There are good reasons why t_{ij} may be nonlinear in its determinants. For example, if country j does not have a container port, then country i will not benefit from its own container facilities in exporting to j.[12] We found that the log linear form fitted the CIF/FOB data considerably better than the linear one.

Several questions have been raised about the use of this CIF/FOB transport cost data.[13] The first is that the measure aggregates over all commodities imported,

11. E-mail correspondence with Mr. Peter Lee at the United Nations.

12. Even if the true transport cost function T^* is linear, there is no reason for the reduced form of the transport cost *rate* t^* to have the same functional form. The reason for this is that for small exporters (facing a perfectly elastic demand) the FOB price, p_i , will itself depend on the average transport cost between themselves and their importers, an effect captured by the reduced form of t^*_{ij}.

13. See Hummels (1998a).

so it is biased if trade on high transport cost routes systematically involves lower transport cost goods. This suggests that our estimates in fact will underestimate the true magnitude of transport costs.[14] The second is the presence of measurement error, arising particularly from the fact that exports are not always accurately reported. To the extent that this measurement error is uncorrelated with the explanatory variables, this should not be a problem.

We deal with three other data problems as follows. First, approximately 25 percent of potential bilateral trade flows are dropped because of missing data from one of the partner countries. Second, some countries had CIF import values lower than the corresponding FOB export values, which would imply negative costs; we dropped all such observations. Third, we also dropped values when they were imputed by the IMF for a CIF/FOB ratio of 1.10. Table A-1 provides further details on sample selection. In section III, we compare the results obtained using the CIF/FOB data with those from the shipping cost data. The comparison indicates that the CIF/FOB data contain information about the cross-sectional variation in transport costs that is consistent with the shipping cost data.

The model is estimated with 1990 data for a sample of 103 countries. Deleting observations that are missing, estimated, or give negative transport costs leaves 4,615 observations. Approximately 22 percent of all country pairs in our sample are reported to have no trade. One important reason for this is that at high enough transport costs two countries will not find it profitable to trade. This implies that for these countries, the transport cost measure is censored at some upper limit and this motivates our use of an upper limit Tobit. We assume that for those countries that report zero trade, the transport cost of trading takes the value of the upper limit in the sample.

Estimation Results

Table 2 gives the results from the estimation of equation 4. The first two rows of the table are characteristics of the journey between *i* and *j*; the log of distance, (ln*distance*), and whether *i* and *j* share a common border (*border*). The remainder are characteristics of the importer country and its trading partner; a dummy for an island (*isldummy* and p*isldummy*); the per capita income of the importing and exporting countries, (ln*Y/cap* and lnp*Y/cap*). Finally, the infrastructure measures (ln*inf* and ln*pinf*) and the infrastructure of transit countries (ln(1 + *inftran*) and ln(1+ p*inftran*)).

The first column of the table gives the effect of distance alone, and the second column gives a specification with journey and country characteristics, apart from infrastructure. Distance and border effects are as expected. Being or trading with an island reduces transport costs (although these effects are barely significant), and high per capita income reduces transport costs. The infrastructure variables are included in the third column, and all are significant with the

14. Hummels (1998b) discusses the cross-commodity variation in transport costs using disaggregated data for four countries.

TABLE 2. The Bilateral Transport Cost Factor, 1990

Variable	1	2	3	4
Distance (ln*distance*)	0.25***	0.23***	0.21***	0.38***
	(6.74)	(6.02)	(5.65)	(10.17)
Common border (*border*)		–1.35***	–1.36***	–1.02***
		(–7.77)	(–7.78)	(–6.30)
Island (*isldummy*)		–0.12***	–0.09	–0.06
		(–1.73)	(–1.23)	(–0.94)
Island (*pisldummy*)		–0.16**	–0.12*	
		(–2.18)	(–1.65)	
Per capita income (ln*Y/cap*)		–0.31***	–0.23***	–0.24***
		(–19.97)	(–9.64)	(–10.78)
Per capita income (ln*pY/cap*)		–0.45***	–0.30***	
		(–27.94)	(–12.84)	
Infrastructure (ln*inf*)			0.34***	0.36***
			(3.92)	(4.47)
Partner infrastructure (ln*pinf*)			0.66***	
			(7.64)	
Infrastructure of transit country		0.21**	0.36***	
ln(1 + *inftran*)			(2.15)	(4.07)
Infrastructure of partner's transit			0.24***	
country ln(1 + *pinftran*)			(2.51)	
				Partner fixed effects
Pseudo-R^2	0.10	0.46	0.48	0.60
σ	1.92	1.70	1.69	1.53

*Significant at the 10 percent level.
**Significant at the 5 percent level.
***Significant at the 1 percent level.

Note: The dependent variable is ln transport cost factor CIF/FOB, lnt_{ij}. All variables are in natural logs, except for the border variables and the island dummies. The sample size is 4,516; Tobit estimates. The pseudo-R^2 is given by the correlation of actual and predicted lnt_{ij}. Constants are included but not reported. Exporter fixed effects are included in column four but not reported. σ is the standard error of the Tobit estimate. *t*-statistics are in parentheses. The Tobit coefficients correspond to the marginal effects for the full sample, including the zeros. See table A-1 for data descriptions and sources and table A-2 for the countries included in the sample. The original transit variable, *inftran*, ranges from 0 for the coastal economies to approximately 1.7. Before taking the log, we add 1 to the measure to correctly reflect that coastal economies bear no extra infrastructure transport cost. To compare the own and transit elasticities, we need to multiply the coefficient of ln*inftran* (reported above) by *inftran* /(1 + *inftran*). This ratio ranges from 0.40 to 0.63 for landlocked countries in this sample.

Source: Authors' calculations.

expected sign. The final column gives results when partner country variables are replaced by dummies for each partner country. As expected, this increases the explanatory power of the equation. The own-infrastructure effects continue to be highly significant.

The results contain several important messages. The first is the quantitative importance of the infrastructure effects. If a country could improve its infrastructure from the median to the top 25th percentile, then its CIF/FOB factor would fall from 1.28 to 1.11, this being equivalent to becoming 2,358 km closer to all its trading partners.[15] Conversely, deterioration in infrastructure from the median to the 75th percentile raises the predicted CIF/FOB factor from 1.28 to 1.40, equivalent to becoming 2,016 km further away from all trading partners.

We can ask a similar question for the border effect. How much closer must two otherwise identical countries be if they do not share a border and are to have the same transport costs? The answer is that they would need to be 932 km closer—compared with a mean distance between capitals of bordering countries of 1,000 km.[16] Thus the positive border effect on trade—which is typically found in gravity model estimates—is very important for transport cost reasons other than distance, suggesting that trans-shipment costs and the integration of transport networks are quite important. We turn to the cost of being landlocked in more detail in section III.

Finally, it is worth comparing our estimates with those using distance, the simple and most commonly used proxy for transport costs. As shown by the pseudo-R^2, using distance alone explains only 10 percent of the variation of transport costs, compared with almost 50 percent when the remaining geography and infrastructure measures are added. Clearly, distance fails to explain a significant part of the variation in transport costs.

II. Trade Volumes

Instead of looking directly at trade costs, we now look at the trade flows they support, by estimating a gravity model including the infrastructure variables used above. There are two main reasons for doing this. First, the variables identified as being important in the transport cost equations should also be important in the trade equations, and we want to confirm that this is so. Second, by using the same variables in estimating transport costs and trade equations, we are able to compute estimates of elasticities of trade flows with respect to transport costs.

The gravity equation is the standard analytical framework for the prediction of bilateral trade flows. Its empirical use in the context of international trade dates back to the early 1960s and theoretical underpinnings were developed later.[17] Despite the abundant number of theoretical derivations of the gravity equation, the majority of the authors do not model transport costs explicitly, exceptions being Bergstrand (1985) and Deardorff (1998). More recently, Bougheas and others (1999) incorporate transport infrastructure in

15. This uses estimates from the fourth column in table 2, and evaluated at the median CIF/FOB ratio of 1.28 and the median distance of 7,555 km, respectively, so 1.11 = 1.28 * (0.95/1.41) ^ (0.36) and 2,358 = 7,555–7555 ** (0.95/1.41) ^ (0.36/0.38).

16. Evaluated at the mean distance for bordering countries of 1,000 km, as new distance = 1,000 * exp(–1.02/.38).

17. See Frankel (1997) for a discussion of earlier references. For different theoretical underpinnings, see Anderson (1979), Bergstrand (1985).

a two-country Ricardian model and show the circumstances under which it affects trade volumes.[18]

Bilateral imports, M_{ij}, depend on GDP in countries i and j (Y_i and Y_j) in the standard way, and on the transport cost factor, t_{ij}, which we model in terms of the geographical and infrastructure measures used in the preceding analysis. Therefore, we have

$$M_{ij} = \varphi Y_j^{\phi_1} Y_i^{\phi_2} t_{ij}^{\tau} \varepsilon_{ij} \quad or \tag{5}$$
$$\ln M_{ij} = \phi_0 + \phi_1 \ln Y_j + \phi_2 \ln Y_i + \tau[\tilde{\beta}'\ln x_{ij} + \tilde{\gamma}'\ln X_i + \tilde{\delta}'\ln X_j] + \eta_{ij},$$

where the second equation is obtained by taking logs and substituting out the true transport cost rate as given by equation 4. We estimate the second equation in expression 5 in the form:

$$\begin{aligned} \ln M_{ij} &= \phi_0 + \phi_1 \ln Y_j + \phi_2 \ln Y_i + \phi_3 \ln distance_{ij} + \phi_4 border_{ij} \\ &+ \phi_5 isldummy_j + \phi_6 isldummy_i + \phi_7 \ln inf_j + \phi_8 \ln inf_i + \phi_9 \ln(1 + inftran_j) \\ &+ \phi_{10} \ln(1 + inftran_i) + \phi_{11} \ln(Y / cap_j) + \phi_{12} \ln(Y / cap_i) + \eta_{ij}, \end{aligned} \tag{5'}$$

where M_{ij} represents country j's imports from i valued cif, Y_i is GDP, *distance* is distance between countries, *border* is whether they share a border, *isldummy* is a dummy for island countries, *inf* is the infrastructure measure, *inftran* is the infrastructure measure for the transit country, and *Y/cap* is per capita GDP.[19] The model is estimated by Tobit using the same data set as for transport costs. In the sample used, 22 percent of all observations are reported as zeros, in which case the import values are set equal to the censoring point, which is the minimum value in the sample.

Estimation Results

Table 3 contains the results of the estimation. Income, distance, border, and island effects have the expected signs, as usual in gravity estimates. The striking result is the strong performance of the infrastructure variables used in the preceding analysis. First, all infrastructure variables (importer, exporter, and transit if either country is landlocked) have the correct sign and are significant at the 1-percent level. Moreover, they have sizable effects on trade volumes. Moving from the median to the top 25th percentile in the distribution of infrastructure raises trade volumes by 68 percent, equivalent to being 2,005 km closer to other countries.[20] Moving from the median to the bottom 75th percentile reduces trade

18. Bougheas and others (1999) estimate augmented gravity equations for a sample limited to nine European countries. They include the product of partner's kilometers of motorway in one specification and that of public capital stock in another and find that these have a positive partial correlation with bilateral exports.

19. The transit infrastructure variables are adjusted for neighboring countries, so if i and j are neighbors and j (i) is landlocked, then $inftran_j$ ($inftran_i$) is set to zero since no transit country must be used. So, to be more precise, in equation 5′ we should write for j $inftran_j{*}(1 - border_{ij})$ not $inftran_j$, and similarly for i.

20. This uses estimates from the fourth column, and evaluated at the median distance of 7,555 km, so 1.68 = (0.95/1.41) ^ (–1.32) and 2,005 = 7,555–7,555 ** (0.95/1.41) ^ (1.32/1.69).

TABLE 3. The Gravity Model of Bilateral Imports, 1990

Variable	1	2	3	4
Income (ln*Y*)	1.28***	1.05***	0.99***	1.03***
	(53.51)	(30.30)	(28.04)	(31.30)
Income of trading partner (ln*pY*)	1.55***	1.35***	1.28***	
	(60.57)	(37.48)	(34.67)	
Distance (ln*distance*)	–1.65***	–1.43***	–1.37***	–1.69***
	(–24.07)	(–18.70)	(–18.03)	(–22.40)
Common border (*border*)		2.45***	2.52***	1.85***
		(7.03)	(7.25)	(5.67)
Island (*isldummy*)		0.48***	0.35**	0.41***
		(3.23)	(2.46)	(3.06)
Island (*pisldummy*)		0.48***	0.40***	
		(3.34)	(2.78)	
Per capita income (ln*Y/cap*)		0.41***	0.16***	0.12**
		(8.78)	(2.96)	(2.28)
Per capita income (ln*pY/cap*)		0.34***	0.16***	
		(7.29)	(3.04)	
Infrastructure (ln*inf*)			–1.32***	–1.32***
			(–7.49)	(–8.07)
Partner infrastructure (ln*pinf*)			–1.11***	
			(–6.26)	
Infrastructure of transit country ln(1 + *inftran*)			–0.60***	–0.77***
			(–3.04)	(–4.18)
Infrastructure of partner's transit country ln(1 + *pinftran*)			–0.45**	
			(–2.26)	
				Partner fixed effects
Pseudo-R^2	0.79	0.80	0.80	0.83
σ	3.47	3.39	3.34	3.08

**Significant at the 5 percent level.
***Significant at the 1 percent level.
Note: The dependent variable is bilateral imports, $\ln M_{ij}$. The sample size is 4,516; Tobit estimates. The pseudo-R^2 is given by the correlation of actual and predicted $\ln M_{ij}$. Constants are included but not reported. σ is the standard error of the Tobit estimate. All variables and sample selection are as in table 2. *t*-statistics are in parentheses.
Source: Authors' calculations.

volumes by 28 percent, equivalent to being 1,627 km further away from trading partners.

III. COMPARISON AND QUANTIFICATION

In this section, we compare the results in a way that facilitates the assessment of the quantitative importance of infrastructure and geographical location for transport costs and trade.

The Cost of Being Landlocked

Table 4 shows the disadvantage of being landlocked, relative to being an average coastal country, for different values of own and transit country infrastruc-

TABLE 4. The Cost of Being Landlocked, Relative to a Coastal Economy, 1990

	Own infrastructure percentile		
Transit infrastructure percentile	25th	Median	75th
Shipping data: transport cost ratio			
25th	1.33	1.48	1.67
Median	1.41	1.55	1.74
75th	1.51	1.65	1.84
CIF/FOB data: (CIF/FOB – 1) ratio			
25th	1.31	1.43	1.65
Median	1.34	1.46	1.69
75th	1.37	1.49	1.72
Gravity model: trade volume ratio			
25th	0.55	0.42	0.26
Median	0.53	0.40	0.25
75th	0.50	0.38	0.24

Note: The construction of the variables for the shipping and CIF/FOB data is as follows: we calculate the predicted transport cost for landlocked countries allowing *inf* and *inftran* to vary as well as the landlocked dummy, but keeping all other variables at the level of the representative coastal country (median value over nonislands). This is then divided by the predicted transport cost (or by CIF/FOB – 1) for the representative coastal country. For the trade volume data, a similar procedure is used. The percentiles are taken over the sample of landlocked countries. The specifications used are column 3 in table 1, column 3 in table 2, and column 3 in table 3. See table A-2 for the countries included in the sample.

Source: Authors' calculations.

ture. The shipping data indicate that the median landlocked country has transport costs 55 percent higher than the median coastal economy. However, improving own infrastructure to the level of the best 25th percentile among landlocked countries cuts this cost penalty to 41 percent, improvement by the transit country cuts the penalty to 48 percent, and if both improvements are made the penalty drops to 33 percent. Using the CIF/FOB measure, table 4 reports ratios of CIF/FOB–1 for landlocked countries relative to the median coastal economy. This gives slightly smaller cost penalties, with the median landlocked economy's transport costs 46 percent higher than the median coastal economy's. Improving own and transit country infrastructure to the 25th percentile reduces this penalty to 34 percent and 43 percent, respectively; if both are improved the penalty drops to 31 percent.

Comparison of these results assures us that the estimates from our different data sources are consistent, and that the cross-sectional variation in the CIF/FOB measure does contain useful information regarding transport costs. Although the CIF/FOB data predict relative costs that are 9 percentage points lower than the shipping data at the median infrastructure values, the partial effects of the own and transit infrastructure variables are similar across the data sets, as illustrated in figure A-1 in the appendix. The similarity between the predicted effects on relative transport costs is particularly striking in the case of own infrastructure.

Table 4 undertakes an analogous experiment for trade volumes, asking how the volume of trade of representative landlocked economies compares with the average coastal economy at the same income levels and distance. The difference is dramatic, with the median landlocked economy having only 40 percent of the trade volume. Improvements in own infrastructure from the median to the 25th percentile increase the volume of trade by 13 percentage points, improvement in transit country infrastructure increase the volume by 2 percentage points, and a simultaneous improvement leads to an increase of 15 percentage points in the volume of trade.

The Elasticity of Trade with Respect to Transport Costs

It is natural to link our estimates of trade volumes and transport costs by computing the elasticity of trade volumes with respect to the transport cost factor as given by the parameter τ in equation 5. In this subsection we offer two approaches to doing this, one based on comparison of the estimates of the CIF/FOB and gravity models, and the other based on regression of trade volumes on predicted trade costs.

The estimates from the CIF/FOB and gravity models (equations 4 and 5) provide overidentifying restrictions for τ, one for each of the determinants in the transport cost equations. We focus on the estimates of distance, border, and own and transit country infrastructure.[21] The elasticities previously found in the gravity estimation ($\hat{\phi}$) and the CIF/FOB estimation ($\hat{\delta}$) are reproduced in the first two columns of table 5. The last column gives the predicted elasticity of trade with respect to the transport cost factor, $\hat{\tau}$, obtained as the ratio of the gravity and CIF/FOB elasticities.

The point estimates of τ vary quite widely, from –6.47 on the distance variable, to –1.67 for the price of infrastructure. The likely reason for this is that some of the variables influence trade volumes through channels other than measured transport costs. For example, distance and border effects might be expected to influence trade volumes through such channels as information flows and language and cultural ties, which would not show up in measured transport costs.[22]

Our second approach is to use predicted values of transport costs (from equation 4) as independent variables in the gravity model (equation 5). In estimating this, we exclude variables that, a priori, we think only affect trade volumes

21. Of the other two variables, it is likely that income per capita may enter the gravity equation for reasons other than transport costs, and the island dummy is not significant.

22. Geracci and Prewo (1977) estimate t for a sample of 18 Organisation for Economic Co-operation and Development (OECD) countries. They find a higher elasticity (τ = –10) than the one we find. This is possibly because of the restriction of their sample to high-income countries. More important perhaps is the fact that they do not estimate an upper limit Tobit for the transport cost. This is likely to lead to an underestimate of the predicted transport cost factor and a consequent upward bias of the transport cost elasticity.

TABLE 5. Estimates of Import Elasticity with Respect to the Transport Cost Factor, 1990

Variable	Elasticity		
	Gravity[a] $\hat{\phi}$	CIF/FOB [b] $\hat{\delta}$	Trade $\hat{\tau} = \hat{\phi} / \hat{\delta}$
Distance (ln*distance*)	–1.37	0.21	–6.47
Import country infrastructure (ln*inf*)	–1.32	0.34	–3.86
Transit country infrastructure ln(1 + *inftran*)	–0.60	0.21	–2.87
Common border (*border*)	2.52	–1.36	–1.85
Partner infrastructure (ln*pinf*)	–1.11	0.66	–1.67
Infrastructure of partner's transit country ln(1 + *pinftran*)	–0.45	0.24	–1.84

Note: We also calculate upper and lower bounds for the trade elasticities using the 95 percent confidence intervals for the gravity and CIF/FOB coefficients. These are *distance* (–4.28, –10.98); ln*inf* (–1.90, –9.75); ln(1 + *inftran*) (–0.53, –53.65); *border* (–1.08, –3.15); ln*pinf* (–0.91, –2.94), and ln(1 + *pinftran*) (–0.14, –15.64).

[a]Gravity elasticities correspond to the estimates in column 3 in table 3.

[b]CIF/FOB elasticities correspond to the estimates in column 3 in table 2.

Source: Authors' calculations.

through transport costs (the infrastructure measures), leaving in those that might affect trade volumes directly. Thus, table 6 reports regressions of trade volumes on predicted values of the transport cost factor, incomes, per capita incomes, and distance and border effects. The first column uses predictions of the transport cost factors from the third column in table 2, whereas the second column has partner fixed effects, so it uses predictions from the fourth column in table 2.

The coefficient on the predicted transport cost factor, $\hat{t}_{ij}$, measures the elasticity of trade volume with respect to the transport cost factor, τ, and, in column 1 in table 6, this is –2.24.[23] Distance remains highly significant, although the coefficient falls markedly compared with the gravity estimates in table 3. This suggests that distance affects trade volumes both through transport costs and independently through other channels, such as information, which could account for the large value of $\hat{\tau}$ associated with the distance coefficients in table 5. Of the other variables, the border coefficient is insignificant, while incomes per capita enter with a negative sign, suggesting that, controlling for transport costs, countries with low per capita income trade more than countries with high per capita income. The second column reports analogous results when partner-country fixed effects are included. The main difference is that this increases the absolute value of the estimated elasticity τ to –3.11, while reducing further the independent role of distance.

Taking tables 5 and 6 together enables us to make an informed judgment about the quantitative importance of transport costs in determining trade flows. Re-

23. Because this is the transport cost factor, an increase from, say, 1.1 to 1.2 is a 9 percent increase, not a doubling.

TABLE 6. Trade Volumes and Predicted Import Costs, 1990

Variable	Based on full model[a]	Based on fixed-effects model[b]
Transport cost factor $\ln(\hat{t}_{ij})$	–2.24	–3.11
	(–10.80)	(–10.01)
Import country income ln*Y*	1.01	1.03
	(29.42)	(31.28)
Export country income ln*pY*	1.26	
	(34.76)	
Import country per capita income (ln*Y/cap*)	–0.25	–0.59
	(–3.23)	(–5.58)
Export country per capita income (ln*pY/cap*)	–0.57	
	(–5.93)	
Distance (ln*distance*)	–0.87	–0.51
	(–9.99)	(–3.74)
Common border (*border*)	–0.50	–1.39
	(–1.14)	(–3.02)
		Partner fixed effects
Pseudo-R^2	0.80	0.83
σ	3.35	3.08

Note: The dependent variable is bilateral imports, $\ln M_{ij}$. The standard error of $\ln(\hat{t}_{ij})$ is not adjusted for the fact that it is a predicted variable, and therefore underestimates the true estimate error.

[a]The dependent variable is from column 3 in table 2.

[b]The dependent variable is from column 4 in table 2.

Source: Authors' calculations.

sults suggest an elasticity of trade flows with respect to the transport cost factor in the range of –2 to –3.5. Taking a value of –3 means that doubling transport costs from their median value (that is, raising the transport cost factor from 1.28 to 1.56) reduces trade volumes by 45 percent. Moving from the median value of transport costs to the 75th percentile (transport cost factor 1.83) cuts trade volumes by two-thirds.

IV. TRANSPORT COSTS, INFRASTRUCTURE, AND SUB-SAHARAN AFRICAN TRADE

Our results show how poor infrastructure and being landlocked damage trade. We now extend the quantitative implications of our findings by applying them to Sub-Saharan African (SSA) trade.[24]

24. Evidence of the importance of transport costs for Africa's export performance is given by Amjadi and Yeats (1995) and Amjadi, Reincke, and Yeats (1996). In the former study, it is reported that, according to balance of payments statistics, SSA's net insurance and freight payments amounted to 15 percent of the value of the exports. By comparison, for all developing countries the payments averaged 5.8 percent. Collier and Gunning (1999, p. 71) provide a brief description of the quantity and quality of infrastructure in SSA.

Is SSA Trade Too Low?

There is a common belief that Africa trades "too little" both with itself and with the rest of the world. Frankel (1997) reports intraregional trade shares in 1990 of 4 percent for Africa compared with 44 percent for East Asia. Amjadi, Reincke, and Yeats (1996) discuss the marginalization of SSA in world trade. The poor performance is typically attributed to protectionist trade policies (Collier 1995; Collier and Gunning 1999) and high transport costs due to poor infrastructure and inappropriate transport policies (Amjadi and Yeats 1995).

This view has been contested by Foroutan and Pritchett (1993), who show that the low level of intra-African trade is explained by the usual determinants of a gravity equation. Similarly, Coe and Hoffmaister (1998) conclude that bilateral trade between SSA countries and industrial countries in the 1990s was not unusually low. Finally, Rodrik (1998) finds that the trade/GDP ratios of SSA countries are comparable to those of countries of similar size and income, and that Africa's marginalization is mainly due to low income growth.

What evidence does our data provide on this, and to what extent can it be accounted for by the infrastructure variables we have identified as being so important? To answer this we reestimated the baseline and infrastructure specifications of our transport cost and gravity models, augmenting them with African dummies: African importer (*Africa*), African exporter (p*Africa*), African importer and exporter (*AA*), and an interaction of the latter with distance (*AAdistance*). Tables 7 and 8 provide the estimates for the transport cost equation and the gravity equation, respectively.

Intra-SSA trade costs are substantially higher and trade volumes substantially lower than those for non-SSA countries. In tables 7 and 8, the Africa factor gives the combined effects of the Africa dummies. Intra-SSA transport costs are 136 percent higher (2.36 = exp(0.08 + 0.52 + 0.26) from table 7) and trade volumes are 6 percent lower (0.94 = exp(–0.23 – 0.59 + 0.76) from table 8). Thus the basic specification cannot account for the poor performance of African trade, even when it controls for both geographical variables (border and island dummies) and per capita income.

In tables 7 and 8, the third and fourth columns add the infrastructure measures. The key finding is that infrastructure accounts for nearly half the transport cost penalty borne by intra-SSA trade. The penalty attributable to the Africa dummies drops from 136 to 77 percent. The Africa penalty on trade flows is actually overturned, suggesting that, once we control for infrastructure intra-SSA trade is 105 percent *higher* than would be expected.

It is sometimes claimed that poor communications infrastructure in Africa entails higher transport costs per kilometer within SSA than elsewhere. We investigate this with the interaction variable *AAdistance*, which is zero for trade involving one non-African country, and equal to distance for trade between a pair of African countries. Foroutan and Pritchett (1993) use a similar variable and find that it is insignificant, which leads them to conclude that "the gravity model gives little evidence that in fact distance is a greater barrier to intra-SSA

Table 7. Transport Costs of Sub-Saharan African Countries, 1990

Variable	1	2	3	4
Income				
Import country (ln*Y*)				
Export country (ln*pY*)				
Distance (ln*distance*)	0.29***	0.23***	0.26***	0.20***
	(7.38)	(5.67)	(6.57)	(4.88)
Common border (*border*)	–1.33***	–0.97***	–1.35***	–1.01***
	(–7.66)	(–5.39)	(–7.72)	(–5.59)
Island dummy				
Import country (*isldummy*)	–0.13*	–0.12*	–0.10	–0.09
	(–1.78)	(–1.68)	(–1.36)	(–1.29)
Export country (*pisldummy*)	–0.12*	–0.11	–0.11	–0.10
	(–1.64)	(–1.55)	(–1.47)	(–1.41)
Per capita income				
Import country (ln*Y/cap*)	–0.29***	–0.29***	–0.23***	–0.23***
	(–15.31)	(–15.36)	(–9.36)	(–9.36)
Export country (ln*pY/cap*)	–0.36***	–0.36***	–0.28***	–0.28***
	(–18.98)	(–19.12)	(–11.56)	(–11.66)
Infrastructure				
Import country (ln*inf*)			0.32***	0.32***
			(3.47)	(3.59)
Export country (ln*pinf*)			0.50***	0.51***
			(5.54)	(5.60)
Infrastructure of transit countries				
Import country ln(1 + *inftran*)			0.21**	0.18*
			(2.13)	(1.81)
Export country ln(1 + *pinftran*)			0.14	0.11
			(1.43)	(1.09)
Africa dummies				
African importer *Africa*	0.08	0.09	–0.02	0.00
	(0.36)	(1.15)	(–0.26)	(0.00)
African exporter p*Africa*	0.52***	0.53***	0.37***	0.39***
	(6.52)	(6.72)	(4.37)	(4.62)
African importer and exporter *AA*	0.26*	–6.05***	0.22	–6.00***
	(1.79)	(–6.57)	(1.52)	(–6.54)
Interaction of *AA* and *distance* (ln(1,000 km))		0.81***		0.80***
AAdistance		(6.93)		(6.85)
Pseudo-R^2	0.47	0.48	0.48	0.49
σ	1.69	1.68	1.68	1.68
Africa factor[a]	2.36		1.77	
Africa (1,000 km)		1.18		0.92
Africa (3,000 km)		2.87		2.21
Critical distance[b]		826		1,110

*Significant at the 10 percent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Note: The dependent variable is ln transport cost factor CIF/FOB, lnt_{ij}. The sample size is 4,516. *t*-statistics are in parentheses. The pseudo-R^2 is given by the correlation of actual and predicted imports. Constants are included but not reported. σ is the standard error of the Tobit estimate. All variables and sample selection are as in table 2.

[a]Africa factor = exp(*Africa* + p*Africa* + *AA*), or exp(*Africa* + p*Africa* + *AA* + *AAdistance* * ln(#km)).

[b]Critical distance, *x*, is given by: 1 – exp(*Africa* + *pAfrica* + *AA* + *AAdistance* * ln(*x*)) = 0.

Source: Authors' calculations.

TABLE 8. The Gravity Models for Sub-Saharan African Countries, 1990

Variable	1	2	3	4
Income				
Import country (ln*Y*)	1.05***	1.05***	1.02***	1.02***
	(27.44)	(27.45)	(26.96)	(26.99)
Export country (ln*pY*)	1.31***	1.31***	1.28***	1.28***
	(33.47)	(33.45)	(32.69)	(32.70)
Distance (ln*distance*)	1.39***	–1.31***	–1.29***	–1.21***
	(17.45)	(16.06)	(–16.29)	(–14.93)
Common border (*border*)	2.34***	1.87***	2.42***	1.98***
	(6.70)	(5.14)	(6.96)	(5.49)
Island dummy				
Import country (*isldummy*)	0.45***	0.44***	0.35**	0.34**
	(3.14)	(3.07)	(2.41)	(2.37)
Export country (*pisldummy*)	0.42***	0.41***	0.37***	0.37**
	(2.89)	(2.83)	(2.57)	(2.53)
Per capita income				
Import country (ln*Y/cap*)	0.41***	0.41***	0.16***	0.16***
	(8.62)	(8.64)	(2.92)	(2.90)
Export country (ln*pY/cap*)	0.32***	0.32***	0.17***	0.17***
	(6.85)	(6.93)	(3.11)	(3.16)
Infrastructure				
Import country (ln*inf*)			–1.44***	–1.45***
			(–7.92)	(–7.99)
Export country (ln*pinf*)			–1.10***	–1.10***
			(–6.03)	(–6.06)
Infrastructure of transit countries				
Import country ln(1 + *inftran*)			–0.62***	–0.58***
			(–3.13)	(–2.91)
Export country ln(1 + *pinftran*)			–0.40**	–0.36*
			(–2.02)	(–1.80)
Africa dummies				
African importer *Africa*	–0.23	–0.25	0.15	0.13
	(–1.29)	(–1.43)	(0.86)	(0.71)
African exporter p*Africa*	–0.59***	–0.62***	–0.31**	–0.34*
	(–3.46)	(–3.58)	(–1.78)	(–1.93)
African importer and exporter *AA*	0.76***	9.18***	0.88***	9.00***
	(2.61)	(4.92)	(3.03)	(–4.89)
Interaction of *AA* and *distance* (ln(1,000 km))		–1.08***		–1.04***
AAdistance		(–4.56)		(–4.46)
Pseudo-R^2	0.79	0.79	0.80	0.80
σ	3.38	3.38	3.33	3.33
Africa factor[a]	0.94		2.05	
Africa (1,000 km)		2.34		4.98
Africa (3,000 km)		0.71		1.59
Critical distance[b]		2,196		4,684

*Significant at the 10 percent level.

**Significant at the 5 percent level.

***Significant at the 1 percent level.

Note: The dependent variable is bilateral imports, lnM_{ij}. The sample size is 4,516. *t*-statistics are in parentheses. The pseudo-R^2 is given by the correlation of actual and predicted imports. Constants are included but not reported. σ is the standard error of the Tobit estimate. All variables and sample selection are as in table 2.

[a]Africa factor = exp(*Africa* + p*Africa* + *AA*), or exp(*Africa* + p*Africa* + *AA* + *AAdistance* * ln(#km)).

[b]Critical distance, *x*, is given by: 1 – exp(*Africa* + p*Africa* + *AA* + *AAdistance* * ln(*x*)) = 0.

Source: Authors' calculations.

trade than it is for other countries. This result goes against the apparently common feeling that the poor quantity and quality of communications and transport infrastructures between SSA countries is a major obstacle to intra-SSA trade."

We find the opposite, with the second and fourth columns in table 7 indicating that the variable is significant in raising transport costs, and the second and fourth columns in table 8 indicating that it is significant in reducing trade volumes.[25] Thus, controlling for infrastructure, African transport costs are 8 percent lower on journeys of 1,000 km, but 121 percent higher on journeys of 3,000 km. One way to summarize the results, including the interaction variable, is to calculate the critical distance above which a pair of African countries faces a penalty compared with a pair of non-African countries. Looking at transport costs, the distance is 826 km, rising to 1,110 km once we control for infrastructure. Looking at trade volumes, the distance is 2,196 km, rising to 4,684 km once infrastructure is included. It is interesting to note that including the infrastructure measures more than doubles the critical distance for trade and that the majority of country pairs in SSA on opposite coasts exceed that critical distance.

Pulling our Africa results together, there are several main conclusions. First, intra-African transport costs are higher and trade volumes lower than would be predicted by a simple model (column one in tables 7 and 8). However, much of this can be attributed to poor infrastructure and to the particularly high cost of distance in Africa. Our results confirm the fact that intra-African trade is concentrated at the subregional level with less east–west trade than would be expected between a pair of otherwise similar countries in the rest of the world.

V. Conclusion

Transport costs and trade volumes depend on many complex details of geography, infrastructure, administrative barriers, and the structure of the shipping industry. In this article, we have used several sources of evidence to explain transport costs and trade flows in terms of geography and the infrastructure of the trading countries, and of countries through which their trade passes.

Table 9 summarizes some of the main results on the impact of infrastructure, reporting levels and changes from the median infrastructure. The results are strongly consistent, although they come from different data sets and measure different things. Thus, deterioration in infrastructure from that of the median country to the 75th percentile raises costs, according to our shipping data, by an amount equivalent to 3,466 km of sea travel or 419 km of overland travel. Using the CIF/FOB ratio, the equivalent distance is 2,016 km. The impact on trade volumes is equivalent to an extra 1,627 km distance.

Linking transport costs to trade volumes, we estimate an elasticity of trade flows with respect to the transport cost factor of around –3. Table 10 summa-

25. The finding in Foroutan and Pritchett (1993) is most likely because the dummy for African countries that export and import and the interaction variable are multicollinear and thus they are not able to identify either. In our sample the correlation between these variables is over 0.9.

TABLE 9. Predicted Effects of Infrastructure on Trade Costs and Trade Volumes, 1990

Variable	Infrastructure percentile 25th	Median	75th
Shipping data			
Transport costs, US$	4,638	5,980	6,604
Sea km, equivalent change	–3,989	0	+3,466
Land km, equivalent change	–481	0	+419
CIF/FOB			
CIF/FOB ratio	1.11	1.28	1.40
Kilometers, equivalent change	–2,358	0	+2,016
Gravity			
Trade volume, percentage change	+68	0	–28
Kilometers, equivalent change	–2,005	0	+1,627

Note: Shipping data are from column 4 in table 1, CIF/FOB data are from column 4 in table 2, and gravity data are from column 4 in table 3.
Source: Authors' calculations.

rizes the implications of this. It indicates, for example, how a doubling of transport costs (from the median value) reduces trade volumes by 45 percent.

The article also presents results on the disadvantages faced by landlocked countries and by African countries. From both the shipping and the CIF/FOB data sets, we see that landlocked countries are disadvantaged. The representative landlocked economy has transport costs 50 percent higher and trade volumes 60 percent lower than the representative coastal economy. However, landlocked countries are able to overcome a substantial proportion of this disadvantage through improvements in their own and their transit countries' infrastructure. Looking at SSA, we see that transport costs are relatively high, and that trade flows are lower than would be predicted by standard gravity modeling both for intra-SSA trade and for African countries' external trade. We find that most of this poor performance is explained by poor infrastructure and by a particular penalty on long-distance (typically cross-continental) trade in Africa.

TABLE 10. Predicted Effects of the Transport Cost Factor on Trade Volumes, 1990

Transport cost factor, τ, selected values	Predicted change in trade volume from median (percent)
1.11 (25th percentile)	+53
1.14	+42
1.28 (Median)	0
1.56	–45
1.83 (75th percentile)	–66

Note: $\tau = -3$.
Source: Authors' calculations.

Shipping costs of the magnitudes reported here have a major impact on income, both because of the direct cost they impose, and because of the gains from trade forgone. However, our results also point to the potential for reducing these costs through investment in infrastructure.

Appendix. Construction of Variables

Own Infrastructure

Each country's infrastructure is measured by an index constructed from four variables: kilometers of road, kilometers of paved road, kilometers of rail (each per square kilometer of country area), and telephone main lines per person. These measures are highly correlated among themselves and identifying each of their influences on transport costs separately is not possible. One possibility would have been to build an index using principal components. However, we have data on all of the measures for only 51 countries. Thus, we first normalize the variables to have the same mean, one, and then take the linear average over the four variables, ignoring missing observations. This is equivalent to assuming that roads, paved roads, railways, and telephone lines are perfect substitutes as inputs to a transport services production function.

Taking the mean over the available observations implicitly assumes that the missing variables take on average the same value as the available variables. This measure was raised to the power –0.3. The reason for this is that infrastructure is an input to a transport services production function that, if Cobb Douglas, might be written as $Y = K^{\alpha}L^{\beta}I^{\chi}$ where I, the index of infrastructure, is exogenous to the transport sector firm. Then for a given output the reduced form of the cost function will be $T = \phi I^{\chi/(\alpha+\beta)}$ where ϕ is a function of the factor prices of private inputs, the technology, and the target output. If there are constant returns to scale to the private inputs, K and L, then our assumption is that $\chi = 0.3$. According to the data, this value implies that the transport cost per kilometer of the worst infrastructure is approximately ten times that of the best one. In the log-linear specifications this scaling is only a choice of units.

Transit Infrastructure

Let L denote a given landlocked country and L_t the set of transit countries L uses to reach the sea (table A-3). Ideally, we weight transit countries' infrastructure by their share of the transit trade. However, available data report solely whether a country is used for transit, so if country L uses n transit countries, the variable *inftran* gives an equal weight of $1/n$ to the infrastructure index of each of those countries. Two caveats should be noted. First, we are assuming that no trade (or the same share of trade for all countries) goes by air. Although this is clearly unrealistic and the share of trade that is airborne is rising, it is still small enough for landlocked countries to justify this assumption. Second, the transport cost from landlocked to neighboring countries should not include transit country costs and thus, when necessary, our variable is adjusted to reflect this fact.

FIGURE A-1. The Transport Cost of Landlocked Countries Relative to an Average Coastal Country

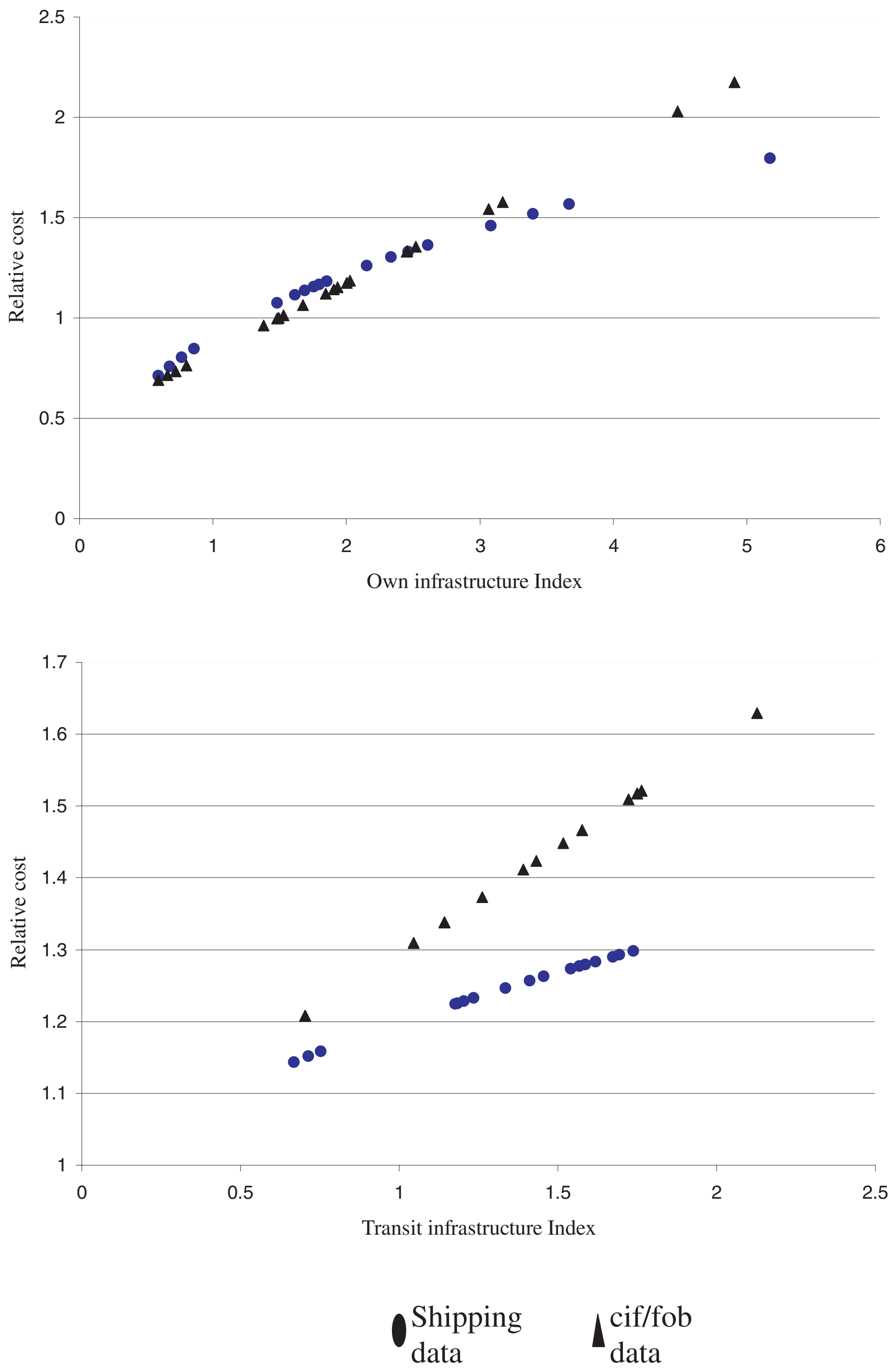

Table A-1. Variable Descriptions and Sources of Data

Variable	Description	Source	Use
distance	Great circle distance between trading partners (1000s km unless ln is used).	Fitzpatrick (1986), authors' calculations	All
distsea	Sea distance around continents from Baltimore to the sea port of landfall (1000s km).	DMA (1985), authors' calculations	Shipping
distland	Great circle distance from sea port of landfall to capital of destination (1000s km).	Authors' calculations	Shipping
border	Dummy variable = 1 if two countries are contiguous or are separated by less than 40 km, 0 otherwise.	CIA (1998)	CIF/FOB, gravity
inf	Inverse of the index of road, paved road and railway densities and telephone lines per capita. A higher value indicates worse infrastructure (see below for more details).	Canning 1998, authors' calculations	All
inftran	Average value of infrastructure for the transit countries if a country is landlocked, zero otherwise. Table A-3 below lists the landlocked countries with respective transit countries used.	Canning 1998, UNCTAD, authors' calculations	All
ldldummy	Dummy variable = 1 if the country is landlocked, 0 otherwise.	CIA (1998)	All
isldummy	Dummy variable = 1 if the country is an island, 0 otherwise.	CIA (1998)	Gravity, CIF/FOB
T_{ij}	Cost of shipping a 40' container from *i* = Baltimore to country *j* (1000s US$, 1999). The mode is surface (as opposed to air), type is freight (as opposed to household goods) and packing is loose (as opposed to lift van where the cargo is packed into wooden containers). The cost does not include insurance.	Panalpina (private communication)	Shipping
M_{ij}	Aggregate imports (inclusive of insurance and freight, CIF) of country *j* from country *i* 1000s current (1990) US$.	IMF (various years)	Gravity
X_{ij}	Aggregate exports (free on board value) of country *i* to country *j* 1000s current (1990) US$.	IMF (various years)	Gravity
t_{ij}	M_{ij}/X_{ij}.	IMF (various years)	CIF/FOB
Y	GDP in current (1990) US$ market prices.	World Bank (1998)	Gravity
Y/cap	Y/population.	World Bank (1998)	All

Note: In the text ln *variable* stands for the natural logarithm of *variable, pvariable* stands for the trade partner's *variable*. There are 103 countries in the sample used in sections I and II. This implies 10,712 potential bilateral pairs. The sample is greatly reduced because 2,759 of the pairs had missing import or export values; 555 had positive imports of *j* from *i*, but exports of zero from *i* to *j*; 2,494 had nonpositive transport costs; and 195 had CIF/FOB between 1.0909 and 1.101.

Table A-2. List of Countries in the Samples
(sorted by quality of own infrastructure)

Shipping data sample			
Belgium	Swaziland	Bolivia	Georgia*
Netherlands	China	Peru	Russia*
Switzerland	Malawi	Lesotho (75th)	Luxembourg*
Austria	Argentina	Burkina Faso	Czech Republic*
Italy	Senegal	Zambia	Azerbaijan*
Germany	Uganda	Benin	Armenia*
Hungary	Kenya (50th)	Nepal	Belarus*
Rwanda	Botswana	Burundi	Kazakhstan*
Uruguay	Cameroon	Bhutan	Kyrgyz Republic*
Turkey	Togo	Mozambique	Macedonia*
India	Côte d'Ivoire	Mali	Moldova*
South Africa (25th)	Ghana	Central African Rep.	Slovakia*
Thailand	Nigeria	Niger	Tajikistan*
Zimbabwe	Congo, Rep. of	Chad	Turkmenistan*
Brazil	Paraguay	Ethiopia*	Uzbekistan*
Chile	Tanzania	Eritrea*	
IMF data sample			
Belgium	Mauritius	Oman	Côte d'Ivoire
Singapore	Spain	Guatemala	Peru
Netherlands	Sweden	Colombia	Bolivia
Switzerland	Costa Rica	Zimbabwe	Benin
Japan	El Salvador	Venezuela	Gabon
Hong Kong, China	India	Gambia, The	Sierra Leone
Denmark	Turkey	Iran, Islamic Rep. of	Haiti
Austria	New Zealand	Honduras	Guinea
United Kingdom	Sri Lanka	Togo	Guinea-Bissau
Germany	Jamaica	Ecuador	Zambia
Italy	South Africa	Malawi	Angola
France	Norway	Saudi Arabia	Congo, Dem. Rep. of
Ireland	Mexico	Egypt, Arab Rep. of	Nicaragua
Hungary	Jordan	Indonesia	Papua New Guinea
Poland	Argentina	Australia	Congo, Rep. of
Israel	Tunisia	Uganda	Burkina Faso
Trinidad and Tobago	Malaysia	China	Nepal
Portugal	Syrian Arab Republic	Kenya	Lao PDR
Finland	Thailand	Paraguay	Madagascar
Romania	Panama	Dominican Republic	Mozambique
Korea, Rep. of	Bangladesh	Senegal	Mauritania
Rwanda	Chile	Ghana	Central African Rep.
Greece	Philippines	Burundi	Mali
United Arab Emirates	Brazil	Algeria	Niger
Uruguay	Canada	Cameroon	Chad
United States (25th)	Pakistan (50th)	Nigeria (75th)	

*Excluded from columns 3 and 4 in table 1 due to missing data for own or transit infrastructure.

Note: Not all country pairs were used due to missing data. Countries with infrastructure values closest to the corresponding sample values are labeled 25th, 50th, and 75th.

Source: For shipping data, see text; for IMF data, IMF (various years).

Table A-3. List of Transit Countries for Landlocked Countries in the Shipping Data Sample and the IMF Data Sample
(sorted by quality of transit country infrastructure)

Landlocked countries	Transit countries
Shipping data sample[a]	
Austria	Germany
Hungary	Germany
Switzerland	Germany
Bhutan	India
Nepal	India
Botswana (25th)	South Africa
Lesotho (25th)	South Africa
Swaziland (25th)	South Africa
Zimbabwe (25th)	South Africa
Zambia	South Africa, Zimbabwe
Paraguay (50th)	Brazil
Bolivia	Chile
Malawi	South Africa, Zimbabwe
Burundi	Kenya
Uganda	Kenya
Rwanda (75th)	Kenya, Tanzania
Central African Republic	Cameroon
Chad	Cameroon
Burkina Faso	Côte d'Ivoire
Mali	Côte d'Ivoire
Niger	Benin
IMF data sample[b]	
Switzerland	Germany, Italy, Netherlands
Hungary	Austria, Italy
Austria	Germany, Italy
Laos PDR	Thailand, Vietnam
Zambia (25th)	Mozambique, Tanzania, South Africa
Zimbabwe (25th)	Mozambique, Tanzania, South Africa
Nepal	Bangladesh, India
Paraguay	Argentina, Brazil, Chile, Uruguay
Bolivia	Argentina, Brazil, Chile, Peru
Central African Republic (50th)	Cameroon; Congo, Rep. of; Congo, Dem. Rep. of
Burundi	Kenya, Tanzania, Uganda
Mali	Burkina Faso, Côte d'Ivoire, Senegal
Rwanda	Burundi, Kenya, Tanzania, Uganda
Chad (75th)	Cameroon, Nigeria
Malawi	Botswana, Mozambique, Zambia, Zimbabwe
Niger	Benin, Burkina Faso, Nigeria, Togo
Burkina Faso	Côte d'Ivoire, Togo
Uganda	Kenya, Tanzania

Note: 25th, 50th, and 75th denote the countries with transit infrastructure values closest to these percentile values.

[a]Transit countries coincide with the port of entry reported by the shipping company. In the case of Zambia and Malawi, Zimbabwe is also a transit country. The countries for which there are no transit or own-infrastructure data (see note in table A-2) are not included here as they were not used in the restricted sample.

[b]Without specific knowledge of the source of the import and transit route, we must take the average infrastructure measure over all the transit countries reported by UNCTAD (see table A-1).

Table A-4. Summary Statistics for Shipping Data Sample, 1998

Variable	Full sample: Mean	Full sample: Standard deviation	Mean: Landlocked countries	Mean: Coastal countries
Whole sample				
Transport cost *T*	6.59	3.50	8.21	4.62
Distance				
Total	9.58	2.39	9.76	9.37
Over sea	10.5	3.75	10.10	10.90
Over land	0.979	1.27	0.979	0.353
Income per capita[a]	4.01	8.11	3.57	4.56
Number of countries	64	64	35	29
Restricted sample[b]				
Transport cost, T	5.98	3.49	7.95	4.38
Distance				
Total	9.75	2.60	10.20	9.37
Over sea	11.20	3.92	11.60	11.00
Over land	0.63	0.57	1.00	0.34
Income per capita[a]	4.21	8.24	3.54	4.76
Number of countries	47	47	21	26

[a]Average for 1990–95.

[b]Countries for which infrastructure data are available. Note that the infrastructure data are available only until 1995. Here we use the average for 1990–95.

Source: Authors' calculations.

Table A-5. Summary Statistics for the IMF Data Sample, 1990

Variable	Mean	Standard deviation
ln*M*[a]	2.89	2.80
ln*t*[a]	0.49	0.62
ln*inf*	0.23	0.47
ln*inftran*	0.11	0.29
ln*distance*	8.49	1.54
border	0.03	0.16
isldummy	0.16	0.36
ldldummy	0.15	0.36
Africa[b]	0.26	0.44
AA[b]	0.07	0.26
AAdistance[b]	7.68	0.91
ln*Y*	24.29	2.26
ln*Y/cap*	7.80	1.66

Note: See table A-1 for variable descriptions and sources. See table A-2 for the country sample.

[a]These values correspond to the uncensored values of the variables. The sample size is 3,577 for those statistics. The median for *t* is 1.28.

[b]The statistics correspond to African partners only. Similar statistics hold for the partner country variables.

Source: Authors' calculations.

TABLE A-6. Quartile Values for the IMF Data Sample, 1990

Variable	Percentile 25th	50th	75th
CIF/FOB (all sample)	1.11	1.28	1.83
CIF/FOB (coastal)	1.10	1.29	1.82
CIF/FOB (landlocked)	1.10	1.23	1.91
inf (landlocked)	1.48	1.82	2.61
inftran	1.18	1.37	1.59
inf	0.95	1.41	1.81
distance	4,536	7,555	10,729
distance (landlocked)	4,078	6,742	9,922

Note: See table A-1 for variable descriptions and sources. All variables correspond to all country samples except for first and last row, which refer to landlocked importers only.
Source: Authors' calculations.

REFERENCES

Amjadi, Azita, and Alexander Yeats. 1995. "Have Transport Costs Contributed to the Relative Decline of African Exports? Some Preliminary Evidence." Working Paper. World Bank, Washington, D.C.

Amjadi, Azita, Ulrich Reincke, and Alexander Yeats. 1996. "Did External Barriers Cause the Marginalization of Sub-Saharan Africa in World Trade?" World Bank Discussion Paper no. 348. Washington, D.C.

Anderson, James E. 1979. "A Theoretical Foundation for the Gravity Equation." *American Economic Review* 69(1):106–16.

Bergstrand, Jeffrey H. 1985. "The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence." *Review of Economics and Statistics* 67(3):474–81.

Bougheas, S. and others. 1999. "Infrastructure, Transport Costs, and Trade." *Journal of International Economics* 47:169–89.

Canning, David. 1998. "A Database of World Infrastructure Stocks, 1950–1995." World Bank Research Paper, Washington, D.C.

CIA. 1998. *World Factbook*. Washington, D.C.: Central Intelligence Agency.

Coe, David T., and Alexander W. Hoffmaister. 1998. "North-South Trade: Is Africa Unusual?" Working Paper of the International Monetary Fund, Washington, D.C.

Collier, Paul. 1995. "The Marginalization of Africa," *International Labour Review* 134(4–5):541–57.

Collier, Paul, and Jan Willem Gunning. 1999. "Explaining African Economic Performance." *Journal of Economic Literature*, 37:64–111.

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

Feenstra, Robert C. 1998. "Integration of Trade and Disintegration of Production in the Global Economy." *Journal of Economic Perspectives* 12(4):31–50.

Fitzpatrick, Gary. 1986. *Direct Line Distances*. Metuchen, N.J.: Scarecrow Press.

Finger, Michael J., and Alexander Yeats. 1976. "Effective Protection by Transportation Costs and Tariffs: A Comparison of Magnitudes." *Quarterly Journal of Economics* 90(1):169–76.

Foroutan, Faezeh, and Lant Pritchett. 1993. " Intra-Sub-Saharan African Trade: Is It Too Little?" *Journal of African Economies* 2(1):74–105.

Frankel, Jeffrey A. 1997. *Regional Trading Blocs in the World Economic System*. Washington, D.C.: Institute for International Economics.

Geracci, Vincent J., and Wilfried Prewo. 1977. "Bilateral Trade Flows and Transport Costs." *Review of Economic Statistics* 59(1):67–74.

Hummels, David. 1998a. "Data on International Transport Costs: A Report Prepared for the World Bank." Development Economics Department, World Bank, Washington, D.C.

———. 1998b. "Towards a Geography of Transport Costs." Department of Economics, University of Chicago, mimeo.

IMF. Various years. *Direction of Trade Statistics*. Washington, D.C.: IMF.

Livingstone, Ian. 1986. "International Transport Cost and Industrial Development in the Least Developed African Countries," *Industry and Development* (19):1–54.

Moneta, C. 1959. "The Estimation of Transport Costs in International Trade." *Journal of Political Economy* 67:41–58.

Radelet, Stephen, and Jeffrey Sachs. 1998. "Shipping Costs, Manufactured Exports and Economic Growth." Harvard Institute for International Development, Cambridge, Mass. Mimeo.

Rodrik, Dani. 1998. "Trade Policy and Economic Performance in Sub-Saharan Africa." NBER Working Paper no. 6562, NBER, Cambridge, Mass.

UNCTAD. 1997. "Selected Basic Transport Indicators in the Landlocked Countries," UNCTAD/LDC/97, United Nations, New York.

———. 1995a. "A Transport Strategy for Land-locked Developing Countries. Report of the Expert Group on the Transport Infrastructure for Land-locked Developing Countries." TD/B/453/Add.1/Rev.1, UN Publications, adopted by the UNCTAD Secretariat, United Nations, New York.

———. 1995b. "Review of Maritime Transport." TD/B/C.4. New York: United Nations.

World Bank. 1998. *World Development Indicators*. Washington, D.C.: World Bank.