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Global Logistics Indicators, Supply Chain Metrics, and Bilateral Trade Patterns

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Abstract

Past research into determinants of international trade highlighted the importance of the basic spatial gravity model augmented by additional variables representing sources of friction. Studies modeled many sources of friction using various proxies, including indices based on expert judgment in some cases. This paper focuses on logistics friction and draws on a data set recently compiled by the World Bank with specific quantitative metrics of logistics performance in terms of time, cost, and variability in time. It finds that the new variables that relate directly to logistics performance have a statistically significant relationship with the level of bilateral trade. It also finds that a single logistics index can capture virtually all of the explanatory power of multiple logistics indicators. The findings should spur public and private agencies that have direct or indirect power over logistics performance to focus attention on reducing sources of friction so as to improve their country's ability to compete in today's global economy. Moreover, since the logistics metrics are directly related to operational performance, countries can use these metrics to target actions to improve logistics and monitor their progress.

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The quality and performance of logistics services differ markedly across countries. In Kazakhstan it takes 93 days to export a 20-foot full container load (FCL) container of cotton apparel, and in Mali 67 days, while in Sweden it takes only 6 days. In Namibia the costs of all trade-related transactions for a 20-foot FCL container, including inland transport from the ocean vessel to the factory gate, amount to slightly more than $3,000, and in Georgia to slightly less than $3,000. In Germany these costs amount to only $813, and in Sweden to a little more than $500.

These variations in time and cost across countries stem from differences in the quality and cost of infrastructure services as well as differences in policies, procedures, and institutions. They have a significant effect on trade competitiveness.

Many empirical studies have examined the effect of transport costs on trade flows. Notably, Limão and Venables (2001) find a robust statistical link between transport costs and international trade flows. They also find a clear link between the quality of infrastructure and transport costs—and thus conclude that infrastructure investments are important for export-led economic growth.

Other studies find that differences in logistics performance are driven only in part by poor quality of physical infrastructure services such as road, rail, waterways, port services, and interfaces (Subramanian and Arnold 2001). Instead, the inadequacies often are caused by (nontariff) policy and institutional constraints—such as procedural red tape, inadequate enforcement of contracts, poor definition and enforcement of rules of engagement, delays in customs, delays at ports and border crossings, pilferage in transit, and highly restrictive protocols on movement of cargo. Consider these differences and their implications for ease of trade: 100 percent of imports coming into Sri Lanka and nearly 100 percent coming into Nigeria are subject to comprehensive inspection, while 2 percent are inspected in Germany and only 1 percent in Canada. A typical export transaction requires 42 approval signatures in the Democratic Republic of Congo, 40 in Azerbaijan, 39 in Nigeria, and 33 in Mali—but only 2 in Australia, Austria, and Canada and 1 in Germany.

Driven by economic liberalization and technological developments, the decentralization of production, marketing, and distribution activities worldwide offers developing economies tremendous opportunities to participate in providing value added services. Participating in global supply chains can improve countries' access to markets and stimulate investment, enhancing employment opportunities. In Bangladesh, for example, the garment sector provides productive employment for more than 1.5 million poor, low-skilled female workers.

But this decentralized environment also poses strong challenges to developing economies, requiring them to be highly efficient, productive, and capable of providing just-in-time services. Efficient logistics services play an essential role in the worldwide flow of goods and services and in the ability of countries to attract and sustain investment. Inefficiencies in logistics have been highlighted as an important constraint on firms' productivity and competitiveness in developing countries by earlier studies on investment climate and trade facilitation ("behind the border" issues). Dollar, Hallward-Driemeier, and Mengistae (2004) find that firms in countries with a better investment climate, including better logistics have a higher probability of exporting to international markets and attracting foreign direct investment. Similarly, Subramanian, Anderson, and Lee (2005) find that long customs clearance times have a significant adverse effect on firms' productivity.

Logistics inefficiencies harm the competitiveness of private firms through their effects on both cost and time. The costs relate not only to the direct costs of transporting products; goods in transit incur indirect costs such as inventory holding costs (see Hausman 2004). The longer the transit time, the higher are the costs. Hummels (2001) finds that shippers are willing to pay a premium for faster delivery.

Other indirect costs are incurred when delivery times and reliability are uncompetitive, severely affecting a country's position in highly competitive international markets demanding just-in-time delivery. Product value often declines with time while in transit. For perishable products, spoilage or wastage may increase with transit time. Products with time-sensitive information, such as newspapers, decline sharply in value as that information becomes obsolete. Seasonal and fashion apparel has similar time sensitivity. These costs can also reflect lost opportunities, as when critical inputs cannot reach manufacturing plants in time or perishable commodities cannot reach markets in time—or when production plants must hold higher-than-optimal levels of raw material inventories to cover for logistics delays.

The purpose of this paper is to examine the effect of logistics cost and time on bilateral trade patterns. The paper uses a supply chain framework to examine the time and cost of importing and exporting a typical 20-foot FCL container with medium-value products for 80 economies. It also includes, for the first time, a more complex dimension of time—certainty in time of delivery. Reliable delivery of goods within narrow time windows, with minimal uncertainty, may be even more important than average delivery time to a firm's ability to compete in just-in-time regimes.

The paper first analyzes comprehensive data for global logistics indicators from the 80 economies. These data show interesting differences across economies, varying by level of development, extent of liberalization, access to coastal ports, and the like. The global logistics indicators most critical for supply chain management are then selected for inclusion in an augmented gravity model. The model incorporates the effects of direct shipping costs as well as time, variability in time, and complexity of procedures, all of which lead to significant indirect costs that harm the export competitiveness of countries. This model incorporates much more detailed and specific information on the components of logistics time and cost than has been used in earlier studies. Incorporating such detailed time and cost information makes it possible to identify the specific policy, institutional, and infrastructural components of international trade—such as inland transport or customs clearance—that are the most serious impediments to trade competitiveness. The analysis finds strong empirical evidence that transaction costs associated with policy and institutional constraints are critical in explaining much of the variation in bilateral trade. The global logistics indicators are generally statistically significant and with the expected sign, indicating that poor logistics performance has a significant adverse effect on bilateral trade.

Next, the paper uses a three-stage estimation process to develop a single logistics index comprising several of the global logistics indicators and shows that this index captures essentially all the explanatory power of the indicators used separately. The final model explains about 71 percent of the variability in bilateral trade in the 80-economy data set. Finally, the paper performs sensitivity analysis on the model with the logistics index to estimate the potential benefits from different improvements in logistics.

Literature Review

The basic framework for the analysis is the gravity model that has been used extensively in the trade literature.[1] The standard gravity model describes bilateral trade as directly related to the size of the two countries involved and inversely related to the geographic distance between them. Recent studies applying the gravity model approach to analyze international trade include

[1] See Anderson (1979) for different theoretical underpinnings. See Frankel (1997) and Cheng and Wall (2004) for a discussion of earlier studies.

McCallum (1995); Helliwell (1998); Frankel, Stein, and Wei (1998); Feenstra, Markusen, and Rose (2001); Limão and Venables (2001); Clark, Dollar, and Micco (2004); Nordås and Piermartini (2004); and de Groot and others (2004).

McCallum (1995) finds that despite the North American Free Trade Agreement (NAFTA) and liberal trade arrangements between the United States and Canada, cross-border trade flows between states and provinces are lower than corresponding domestic flows, even after controlling for distance and other economic factors. McCallum uses distance and the presence of the border as transfer cost measures, but does not explicitly include information on transport cost or time.

Limão and Venables (2001) use a gravity model that explicitly includes transport costs, in addition to distance, in analyzing bilateral trade flows. Their measure of transport costs incorporates an infrastructure index (a composite of transport and communications networks). They find that the quality of infrastructure in the origin and destination countries has significant effects on transport costs; moreover, inland transport costs are around seven times ocean transport costs. Their estimations of the elasticity of trade flows with respect to transport costs are in the range of –2 to –3.5. Increasing trade costs by 10 percent reduces trade volumes by more than 20 percent.

Clark, Dollar, and Micco (2004) estimate a log-linear gravity model of trade to estimate the effect of transport costs on bilateral trade. Their gravity model incorporates an extensive series of explanatory variables, including distance, GDP, common language, and land border dummy variables as well as a dummy variable on whether the countries had a common colonizer. The authors show that port efficiency plays a significant part in determining transport costs. And transport costs are highly significant determinants of bilateral trade, with the expected negative sign.

None of the studies cited above takes explicit account of transport time as distinct from cost. Hummels (2001) is among the first to do so. His model includes both distance and shipping time (in days) in a model of imports from 200 countries to the United States, by ocean and by air. Using cost (by mode of transport) and shipping time for each bilateral trade flow, he estimates the implicit value of time saved in shipping time. He estimates that each day in shipping time reduces the probability of trade by 1 percent (for all goods) and 1.5 percent (for manufactured goods).

Recent research by de Groot and others (2004) highlights institutional quality as an explicit determinant of bilateral trade, recognizing that the performance of institutions can have a significant impact on transaction costs, which in turn affect trade. To examine bilateral trade, the authors use an augmented gravity model that, in addition to distance and the GDP of each country, includes dummy variables for common border, common language, common trade area, and common religion and a set of variables representing institutional quality (voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption). The analysis controls for multicollinearity and includes a composite institutional quality index. Results show that increasing the overall quality of institutions above its mean would significantly increase bilateral trade.

This paper extends the analyses of de Groot et al. (2004) and Hummels (2001) in several respects. First, it uses bilateral trade data from 2003, thus updating the data by five years.[2] Second, it uses a new data set, the first of its kind, which contains quantitative, country-level data on important aspects of trade logistics, including inland transport and trade-related transactions, using concrete metrics of cost and time. Thus it extends Hummels's model by expanding the transport time measure to include time for document processing, customs clearance, and inland transport, and to include timeliness (or variability in time) rather than average time only.

Data

The data set, compiled by the World Bank in 2005, contains detailed country-level data on the time and cost of moving a typical 20-foot FCL container from the port of entry to a firm in the most populous or commercially active city in the country—or to the port of exit from a firm in that city.[3] The use of a disaggregated supply chain framework makes it possible to measure time and cost for such activities as trade document processing, approvals needed for import or export transactions, customs clearance, technical clearances, inland transport, terminal handling, and container security measures. In addition, the data illuminate underlying policy and institutional issues that affect time and cost along the supply chain, such as the percentage of containers inspected, the number of agencies with the power to inspect goods, and whether risk-based criteria are used for inspections.

[2] The data set includes either 2003 data or the most recent data available as of August 2005. Of the 80 economies, 70 had 2003 data available, 6 had 2002 data, 2 had 2001 data, 1 had 2000 data, and 1 (Angola) had 1999 data.
[3] The survey excluded ocean freight time and cost, since that would have involved an extremely large number of bilateral trade partners for each country. It included distance, however, used as a surrogate for shipping cost.

The survey instrument used to collect the logistics data is a detailed questionnaire distributed to experienced logistics practitioners (freight forwarders) in 140 economies.[4] The aim was to focus on the detailed policy and institutional issues reflected in actual operational practices faced day to day in a country by private firms and by the freight forwarders serving as their intermediaries. Freight forwarders are in an excellent position to provide information on logistics, since private firms in most countries use the services of freight forwarding companies to ship their products into and out of the country.[5]

A pilot survey of 17 carefully selected economies representing different regions and income levels was used to refine the questionnaire before its use in the larger set of economies. The survey asked separately about imports and exports. In addition, because landlocked economies face a unique set of difficulties, these were separated from coastal economies.

This paper uses the results for 80 of the 140 economies covered by the survey: 17 in Sub-Saharan Africa, 12 in Central and Eastern Europe, 12 in Latin America and the Caribbean, 11 in East Asia, 8 in the Middle East and North Africa, and 5 in South Asia, as well as 15 major industrial countries (see appendix table A.1)[6]. The economies in the data set range widely across regions, income levels, and extent of economic liberalization, and some face the special challenges of being landlocked and therefore dependent on transit countries' infrastructure services for access to ports. The sample includes 70 coastal and 10 landlocked economies.

To ensure that the data reflect the conditions that a typical firm or intermediary would encounter, survey participants were asked to base their responses on the institutions and services faced by the typical medium-size firm in a country—not on cases where there might be "special conditions or privileges," such as for firms located in a free trade zone. In Bangladesh, for example, a garment manufacturer located in an export processing zone might be able to clear a container of raw material imports within a day. But for a garment manufacturer located outside the zone, it would take 9 days to clear a similar container through customs alone and another 8 days for port and terminal handling through Chittagong port. It is this case, indicating conditions in Bangladesh for a typical manufacturer, that the survey was designed to capture. To guide the responses of practitioners to reflect these "on the ground" physical, policy-related, and

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[4] Paul Roberts (a former faculty member and director of the Massachusetts Institute of Technology's Center for Transportation and Logistics) and Peter Yee (with Consilium International Inc.) were involved in designing this questionnaire.
[5] Panalpina, with a worldwide network of offices and agents, was the primary provider of the data. In some countries other forwarding agencies provided supplementary information.

[6] Selected key logistics indicators for the remaining 60 countries are also available. The data for the 80 countries were more comprehensive especially on the cost figures.

institutional conditions, a case study approach with a carefully thought-through framework was adopted for the questionnaire. The case study included a number of assumptions about the firm, traded goods, and procedures.

Assumptions about the firm

Survey participants were asked to base their responses on a medium-size firm with 200 or more employees. The firm was assumed to be a private, limited liability company, formally registered, and operating under commercial laws and regulations of the country. To control for any special exceptions relating to foreign or joint ownership, the firm was also assumed to be domestically owned, with no foreign ownership.

The firm was assumed to be located in the country's most populous city and to export at least 10 percent of its products internationally. Its trade with international partners takes place by ocean transport. The port closest to or most used by the most populous city serves as the port of entry and exit.

The logistics system and services serving the most populous city were the focus of the questionnaire in each country. The most populous city was assumed to be among the most commercially active cities in most countries in the data set. Because the survey focused on the most populous city in a country, the data are believed to provide lower-bound estimates of the cost, time, and complexity of moving goods across borders. Firms in the hinterland inevitably face longer delays and greater constraints because of both bureaucratic complexity and physical infrastructure services. Subramanian, Anderson, and Lee (2005) find that the productivity of firms in Chengdu, China, suffers much more from poor logistics than the productivity of those in the eastern part of coastal China, such as in Shanghai and Tianjin. Similarly, in Brazil firms in the northeast show significantly more impact from poor logistics than those in São Paulo.

Assumptions about traded goods

The survey limited the traded goods in the case study to ordinary manufactured products, neither particularly high nor particularly low in value. Some logistics factors, such as customs clearance and technical clearances, depend on the type of industry, the type of product, or both. For example, agricultural and fresh food products would involve greater technical requirements and more agencies than many manufactured products; others might involve special phytosanitary (plant quarantine) or environmental inspection requirements. Similarly, the costs of moving containers would be much higher for frozen products or for goods requiring special security. To control for these factors, the survey asked respondents to focus the case study on a manufactured product that is of medium value; is transportable in a dry-cargo, 20-foot FCL container; requires no refrigeration or special environmental conditions; requires no special phytosanitary or environmental standards check; and includes no hazardous material or military equipment.

To produce indicators that are robustly comparable across 140 economies ranging from Australia, Norway, and the United States to Burundi, Malawi, and Nepal, three SITC (Standard International Trade Classification) codes were chosen to specify the type of product being traded:

- SITC 65: Textile yarn, fabrics, made-up articles.
- SITC 84: Articles of apparel and clothing accessories.
- SITC 07: Coffee, tea, cocoa, spices, and manufactures thereof.

An examination of world trade data confirmed that most economies in the sample trade in these products.[7]

Assumptions about procedures

A procedure for which the time and cost were measured was defined as any interaction of the firm with external parties (government agencies or officials, inspection agencies or officials, port officials, customs, and the like). Intrafirm interactions among employees were excluded. All procedures that are legally or in practice required for trading or shipping a containerized product were recorded, even if they may be avoided in exceptional cases.

An important issue to control for was simultaneity of procedures. When two or more procedures are simultaneously performed, the time for the entire transaction (import or export) cannot be obtained by summing the time for individual procedures. A separate question in the questionnaire made it possible to identify and correct for simultaneously completed procedures.

Missing or inconsistent responses

The questionnaire was carefully designed to provide consistency checks across responses. Where gaps or discrepancies were noted, follow-up telephone calls were made to the source to resolve the discrepancy or fill in the missing data. The cost data presented particular difficulties, requiring substantial efforts to follow up with the original source as well as other sources in most countries to complete or correct the data. If several sources had different estimates of time and cost, the median value was used.

[7] The world trade data are from the United Nations Statistics Division - UN Commodity Trade Statistics Database

Measurement issues

The analysis in this paper uses four key metrics for measuring the performance of trade logistics services: the cost of processing a typical import or export transaction, the average time required to process a typical import or export transaction, the variation in time for completing an import or export transaction (reflecting uncertainty in time), and the complexity of transactions (as reflected by red tape and bureaucratic variables such as the number of documents required, the percentage of containers inspected, and the criteria for inspection).

Survey respondents were asked to indicate direct costs in the form of all charges and fees across all the procedures. Inland transport charges account for a significant share of the direct costs of trade logistics; inland locations are therefore at a distinct competitive disadvantage relative to coastal locations. The size of this disadvantage depends not only on the distance from the port but also on the extent and condition of road and rail infrastructure. The disadvantage is even greater for landlocked countries. Without appropriate pricing mechanisms, transit countries may have little incentive to provide adequate infrastructure for shipments originating in landlocked countries. In addition, landlocked countries face additional border clearance procedures associated with transit countries. For many landlocked countries in Africa (Burundi, Botswana) and South Asia (Bhutan, Nepal) inland transport and additional transaction costs add significantly to the cost and especially the time of shipments. For landlocked Zambia, for example, costs of trade-related transactions for a 20-foot FCL container amount to $4,616, compared with $969 in Côte d'Ivoire.

Institutional issues such as customs inspection and clearance, technical clearance, and document processing are among the most important factors in the cost and time of shipments, more important even than the physical condition of roads or rail (Subramanian 2001; Subramanian and Arnold 2001). Customs clearance times range from about 1 day for Hong Kong (China) and the Netherlands and 2 days for Ireland and Mauritius to 21 days for the Syrian Arab Republic and 25 days for Uzbekistan. Such procedural reforms as standardizing paperwork, streamlining inspection procedures, and allowing goods to transit in bond can markedly improve the situation.

The efficiency of port and terminal operations is a critical factor in both cost and time. Many ports in developing countries lack adequate capacity for container operations—a major problem, since containerization at the earliest possible stage in the logistics chain is essential for participating in global markets. In addition, containers are still physically and manually inspected in many developing countries. Often these inspections cover all containers. For example, the Arab Republic of Egypt, Georgia, Sri Lanka, Vietnam, and Yemen inspect 100 percent of import containers. Decisions to inspect all containers are not necessarily driven by lack of scanning technology. Instead, they often reflect a lack of risk-based management criteria resulting from policy or procedural anomalies. Poor management and labor union difficulties also adversely affect the efficiency and productivity of ports. When Chittagong port in Bangladesh is closed, 75 percent of the time the closure is due to labor strikes and only 25 percent of the time to natural causes such as storms.

Port efficiency affects vessel turnaround time and thus costs. Vessel turnaround time averages 7 days in Algeria, Nigeria, and the Russian Federation, but only 2 days in Germany and 1 day in the United States. Clark, Dollar, and Micco (2004) find that differences in port efficiency between countries can have a cost effect equivalent to differences of 5,000 miles in distance of shipment. They also find that ports offering the best quality of service generally charge the lowest fees.

Hummels (2001) finds that each additional day of transit time for a country's trade would reduce the probability of the United States sourcing from that country by 1–1.5 percentage points. He argues that transport time influences the volume of trade for two reasons:

- Because goods that are in transit constitute inventory for the buyer or the seller (depending on where the buyer takes ownership), longer transport time translates into higher inventory carrying costs (see Hausman 2004).
- Goods awaiting inspection or intermodal transfer may also incur warehousing costs. The value of some goods depreciates with time after their shipment from the point of origin.

Reliability and consistency in delivery time are also critical. In addition to the average time for delivery of a product, what matters in global value chains is the reliable delivery of goods within narrow time windows, with minimal uncertainty in time. This is true for consumer goods as well as for intermediate goods in global value chains that thrive on just-in-time inventories. For example, automotive, electronics, and computer hardware industries maintain low inventories and orchestrate orders across producers worldwide, requiring highly responsive suppliers that maintain consistency in delivery time. Similarly, highly efficient retail chains source consumer products such as apparel globally and demand guaranteed deliveries within very narrow time windows. Since apparel orders may be placed weeks or even months in advance, timeliness becomes critical. The supply chain will incur a cost if the goods arrive either early or late. If they arrive early, the shipper may have to pay to warehouse them until the purchaser takes delivery. If they arrive late, the purchaser may refuse to take delivery, which means markdowns or outright returns.

Global Logistics Indicators

An initial screening of all items in the questionnaire produced an extensive set of possible logistics indicators (table 1), including selected additional indicators for landlocked economies (table 2).[8] The research initially focused on a small number of global logistics indicators (for both exporter and importer) that theoretically would be important for supply chain management, based on time, cost, variability, complexity, and risk factors (see Hausman 2004 and Lee and Whang 2005):

- Total time for trade-related procedures (average and maximum number of days).
- Total cost for trade-related procedures.[9]
- Total time for document processing (days).
- Total number of documents per trade transaction.
- Number of signatures per trade transaction.
- Time to resolve customs appeals (average and maximum number of days).
- Shutdown of port due to natural disaster and labor dispute (days per year).
- Vessel turnaround time (days).
- Percentage of containers inspected.

[8] Many of these indicators are of independent interest. Selected indicators are published in World Bank (2005) as well as on the Web at http://rru.worldbank.org.
[9] Costs are in international dollars (U.S. dollars adjusted for purchasing power parity). Only the costs from the imports section of the questionnaire are used.

Table 1. Logistics Indicators (Possible Set)

Indicators of time

- Total time for trade-related procedures (average and maximum)
    - Customs inspection clearance time (average and maximum)
    - Technical control clearance time (average and maximum)
    - Time for trade document procedures (average and maximum)
    - Inland transport time
    - Additional time due to Container Security Initiative
- Vessel turnaround time (average)
- Time to resolve customs appeals (average and maximum)
- Vessel waiting time to obtain berth

Indicators of cost

- Total cost for trade-related procedures
    - Port- and terminal-related charges
    - Total cost for trade document procedures
    - Border control costs
    - Inland transport cost
    - Additional cost due to Container Security Initiative

Indicators of complexity and risk factors

- Total number of documents per trade transaction
- Number of signatures per trade transaction
- Criteria for customs inspection
- Percentage of containers inspected
- Level of customs inspection
- Damage or pilferage as percentage of value of container
- Shutdown of port due to natural disaster and labor dispute (days)
- Whether the port is a signatory to the Container Security Initiative
- Speed (inland transport by trucks) (kilometers per day)
- Frequency of vessel calls at port
- Number of agencies that have the power to inspect goods
- Number of times consignments are typically inspected
- Percentage of containers electronically scanned
- Percentage of containers physically inspected

Source: World Bank, Global Logistics Indicators Survey, 2005.

Table 2. Additional Possible Logistics Indicators for Landlocked Economies

- Waiting time at border crossings (average and maximum)
- Inland freight cost (through transit country)
- Harmonization of documents with transit country
- Number of transit countries crossed
- Number of borders crossed
- Whether there is free transit access for vehicles across borders

Source: World Bank, Global Logistics Indicators Survey, 2005.

Several of these global logistics indicators turned out to be highly correlated with one another, so they are included in the analysis one at a time to avoid multicollinearity problems. In addition, several have very sparse data (notably the time to resolve customs appeals and the frequency of port shutdown). Based on a preliminary assessment of the indicators, a smaller subset was selected for inclusion in the analysis. In addition, in line with the basic gravity model framework, in which trade between countries is an increasing function of their size or income and a decreasing function of distance between the countries (Frankel and Rose 2002), the following indicators are also included:[10]

- GDP of exporting country.
- GDP of importing country.
- Distance between countries (kilometers).

A dummy variable for regional trade agreements or trade blocs is also included, as well as additional variables that are described as they enter the model.

Augmented Gravity Model Results

Specifications 1–3 in table 3 contain the initial set of models fitted, before any of the global logistics indicators or additional variables are included. Specification 1 contains regressions of bilateral trade on GDP in the exporting and importing country. Specification 2 adds the distance variable, and specification 3 adds GDP per capita of the exporting and importing country. The results are qualitatively consistent with those of earlier studies, particularly de Groot et al. (2004, table 2). Also as expected from earlier research, the dummy variable for regional trade agreements (included in specification 4) is significant.

Next, specifications 5–13 in table 3 include, one at a time, the set of global logistics indicators described in the previous section. Most have coefficients with the expected negative sign and are statistically significant; three are not statistically significant. Thus it can be concluded that most of the global logistics indicators have a significant effect on bilateral trade, in the expected direction.

[10] The data for GDP are from the World Bank's World Development Indicators database. The data for distance are from Gleditsch and Ward (2001), except for Hong Kong (China), for which the source is http://www.wcrl.ars.usda.gov/cec/java/capitals.htm.

One noteworthy result: while the time variability measure for the exporting country is statistically significant, that for the importing country is not. Thus exports from a country are strongly affected by the reliability of its own logistics services but less so by the reliability of services in the importing trade partner.

From the set of global logistics indicators shown to be significantly related to bilateral trade volumes in table 3, supply chain management considerations are used to select those to include in further analysis (since they are highly correlated, multicollinearity precludes using all of them). As noted, standard metrics for supply chain management performance include time, cost, and variability (see Hausman 2004). High values for any of these metrics mean costly and inefficient supply chains. So only these global logistics indicators are included in the remaining gravity models.

Specification 14 in table 4 includes these critical global logistics indicators along with the standard variables described earlier. All the variables in this specification have significant coefficients, with the expected sign, except for the importing country's GDP per capita and time variability measure. Importers may view unpredictable port delays in their own country as a sunk cost for sourcing products from abroad by ocean transport.

Table 3. Initial Extended Gravity Model Estimations

Dependent variable: Total bilateral exports (in logs)

	Specification												
Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
Log of exporter's GDP	1 326	1.396	1.202	1.193	1.199	1.203	1.199	1.193	1.195	1.203	1.193	1.201	1.198
	(68.19)	(82.96)	(63.12)	(62.78)	(62.94)	(62.99)	(63.08)	(63.07)	(62.99)	(63.68)	(62.76)	(63.91)	(64.19)
Log of importer's GDP	1 007	1.049	0.915	0.906	0.909	0.897	0.909	0.909	0.909	0 92	0.909	0.905	0.950
	(54.76)	(65.29)	(46.15)	(45.33)	(45.96)	(45.22)	(44.51)	(45.46)	(45.62)	(45.95)	(44.67)	(45.34)	(47.85)
Log of distance		-1.484	-1.426	-1.397	-1.401	-1.395	-1.387	-1.393	-1.396	-1.423	-1.398	-1.423	-1.386
		(-41.45)	(-40.55)	(-38.22)	(-38.64)	(-38.41)	(-37.83)	(-38.05)	(-38.15)	(-38.94)	(-38.30)	(-39.4)	(-38.2)
Log of exporter's GDP per capita			0.535	0.551	0.326	0.285	0.514	0.539	0.47	0.328	0.551	0.337	0.565
			(17.77)	(18.02)	(7.44)	(6 60)	(16.65)	(13.66)	(13.18)	(8 02)	(18.01)	(8 52)	(18.88)
Log of importer's GDP per capita			0.358	0.375	0.151	0 24	0.375	0.302	0.315	0.237	0.362	0.321	0.051
			(11.22)	(11.73)	(3 39)	(5 87)	(11.72)	(7 51)	(8.44)	(5.42)	(10.53)	(8.41)	(1.26)
Log of exporter's average time for all procedures					-0.559								
					(-7 93)								
Log of importer's average time for all procedures					-0.521								
					(-7 65)								
Log of exporter's maximum time for all procedures						-0.875							
						(-9 36)							
Log of importer's maximum time for all procedures						-0.525							
						(-5.78)							
Log of exporter's MaxTime-AvgTime difference							-0.325						
							(-5 92)						
Log of importer's MaxTime-AvgTime difference							0.044						
							(0 56)						
Log of exporter's average time for document processing								-0 03					
								(-0 59)					
Log of importer's average time for document processing								-0.155					
								(-3 21)					
Log of exporter's total number of documents required									-0.577				
									(-4 66)				
Log of importer's total number of documents required									-0 27				
									(-3.43)				
Log of exporter's total number of signatures required										-0.446			
										(-8.42)			
Log of importer's total number of signatures required										-0.201			
										(-4.73)			
Log of importer's vessel turnaround time											-0.047		
											(-1 09)		
Exporter's percentage of containers inspected												-0.010	
												(-7 94)	
Importer's percentage of containers inspected												-0.003	
												(-2.7)	
Log of importer's total cost of import-related procedures													-0.590
													(-13.62)
Regional trade agreement dummy variable				0 23	0.202	0.193	0.236	0.218	0.225	0.195	0 23	0.232	0.282
				(3.19)	(2 81)	(2 68)	(3 26)	(3 01)	(3.12)	(2.72)	(3.18)	(3 24)	(3 89)
K	3	4	6	7	9	9	9	9	9	9	8	9	8
R -squared	0 567	0.669	0.694	0.694	0.701	0.702	0.696	0.695	0.696	0.700	0.694	0.700	0.706
Adjusted *R* -squared	0 567	0.669	0.694	0.694	0.701	0.702	0.696	0.695	0.696	0.700	0.694	0.699	0.705
Observations	5149	5149	5149	5149	5149	5149	5149	5149	5149	5149	5149	5149	5149
F -statistic	3443 0	4032.2	2656.4	2207.6	1725.2	1722.4	1660.3	1666.6	1926.0	1677.8	1895.3	1720.6	2015.6

Note: Dependent variable is total bilateral exports (in logs) in 2003 or latest year available. Figures in parentheses are *t* -statistics (based on robust standard errors). Constant terms are not shown.
Source: Authors' calculations.

Based on the finding by de Groot et al. (2004) that institutional quality is important in explaining bilateral trade flows, the Corruption Perception Index is added to the model to represent institutional quality for both the exporting and the importing country (see table 4, specification 15).[11] These variables have the expected positive coefficients and are statistically significant.

Moreover, as de Groot e (2004) and Anderson and Marcouiller (2002) also find, when institutional quality is included, the coefficients of the GDP per capita variables become insignificant or have the wrong sign. This result could be explained by multicollinearity among the institutional quality variables and GDP per capita. Thus GDP per capita is omitted from further analysis. Specification 16 in table 4 contains the results: omitting GDP per capita reduces the adjusted *R*-squared value only slightly, while it improves the coefficients of many of the statistically significant variables.

[11] The analysis uses the Corruption Perception Index for 2004, from Transparency International (the index has a scale of 0–10, with 10 being least corrupt). Alternative variables to represent institutional quality were also tried, such as rule of law, regulatory quality, and control of corruption (all from the World Bank's Governance Research Indicator Country Snapshot) and contract enforcement and registering property indices (from the World Bank's Doing Business database). Because these alternative variables all turned out to be strongly correlated with the Corruption Perception Index, that index is the only one retained in the model.

Table 4. Augmented Gravity Model Estimations

Dependent variable: Total bilateral exports (in logs)

	Specification		
Variable	14	15	16
Log of exporter's GDP	1.207	1.251	1.265
	(64.35)	(64.77)	(75.57)
Log of importer's GDP	0.962	1.000	0.956
	(47.38)	(48.23)	(54.17)
Log of distance	-1.383	-1.395	-1.390
	(-38.27)	(-38.64)	(-39.02)
Log of exporter's GDP	0.323	0.082	
per capita	(7.46)	(1.46)	
Log of importer's GDP	-0.001	-0.195	
per capita	(-0.02)	(-3.59)	
Log of exporter's average time	-0.519	-0.349	-0.373
for all procedures	(-7.37)	(-4.68)	(-5.24)
Log of importer's average time	-0.137	0.124	0.171
for all procedures	(-1.87)	(1.53)	(2.13)
Log of exporter's MaxTime-AvgTime	-0.273	-0.235	-0.236
difference	(-5.07)	(-4.25)	(-4.28)
Log of importer's MaxTime-AvgTime	0.189	0.120	0.090
difference	(2.45)	(1.57)	(1.18)
Log of importer's total cost	-0.569	-0.518	-0.492
of import-related procedures	(-12.14)	(-11.0)	(-10.68)
Exporter's Corruption Perception Index		0.165	0.188
		(7.2)	(10.82)
Importer's Corruption Perception Index		0.183	0.134
		(7.22)	(6.27)
Regional trade agreement	0.270	0.332	0.343
dummy variable	(3.71)	(4.58)	(4.73)
K	12	14	12
R-squared	0.712	0.717	0.717
Adjusted *R*-squared	0.711	0.717	0.716
Observations	5149	5149	5149
F-statistic	1305.7	1101.0	1287.0

Note: Dependent variable is total bilateral exports (in logs) in 2003 or latest year available. Corruption Perception Index is for 2004, from Transparency International. Figures in parentheses are *t*-statistics (based on robust standard errors). Constant terms are not shown.
Source: Authors' calculations.

Total Landed Cost Model and Logistics Index

Another approach to explaining bilateral trade takes a supply chain management orientation and attempts to estimate the total landed cost of product exported from different countries. Other things equal, an importing company would prefer a source with lower total landed cost. While total landed cost is only one of many important factors in global sourcing decisions by private firms, it is often cited as an important metric (see Pyke 2005). Total landed cost has the following components:[12]

- Product cost[13].
- Transport (shipping) cost.
- Trade-related costs (processing, customs clearance, port operations, and the like).
- Inventory holding cost for pipeline (in-transit) inventory.
- Inventory holding cost for safety stock inventory.

Safety stock refers to inventory held to cope with unpredictable variations in either demand or supply. Virtually all supply chains face variable (unpredictable) demand to some extent, and many supply chains also face variable lead times on the supply side. Logistics operations and sourcing choices affect lead times, and standard inventory control theory suggests that there is a square-root relationship between lead time and the amount of safety stock required (see Bonini, Hausman, and Bierman 1997, chapter 8). Moreover, if a particular country has highly variable processing times for port operations, supply chain managers need to hold additional safety stock to maintain desired customer service levels in the face of increased supply uncertainty.

Here the components of total landed cost are combined into a single index, referred to as a logistics index. Combining several logistics indicators into a single index has several benefits, as long as that index captures essentially all the explanatory power of the original full model:

- A single metric can allow countries to evaluate and measure their logistics efficiency.
- The coefficients of the variables in the logistics index would show the relative payoff of different initiatives to improve logistics, helping to determine the most effective resource allocation to and deployment of such initiatives in a country.
- A single measure allows quick and easy benchmarking.

[12] Some definitions exclude the inventory holding cost components that are included here.
[13] Product cost is not included in the analysis and determination of the Logistics Index.

The logistics index is estimated in three stages. The first stage involves fitting a simple gravity model that includes the following standard variables:

- GDP of both exporting and importing country.
- Corruption Perception Index of both exporting and importing country.
- Regional trade agreement dummy variable.

The second stage attempts to explain the residuals of the first-stage regression using the following set of logistics indicators, which represent the components of total landed cost:

- Distance (a surrogate for shipping cost).
- Total processing cost (a direct measure of trade-related costs).
- Total time (document processing, inland transport, customs, port and terminal) (a surrogate for the holding cost for in-transit inventory).
- Coefficient of variation for total time[14] (a surrogate for the holding cost for safety stock).

The second-stage regression derives the optimal coefficients (weights) for these total landed cost variables to best explain the residuals from the first stage. If the components of total landed cost are important determinants of global trade, this second-stage regression would be expected to have statistically significant explanatory power.

The third stage uses the coefficients derived in the second stage to create a single logistics index[15] and employs that index in place of multiple separate total landed cost variables in an augmented gravity model. If this single logistics index performs reasonably well in explaining bilateral trade flows, it can then be argued that the index systematically captures the various components of total landed cost.

Table 5 shows the results of these three stages. The second-stage adjusted *R*-squared value is 0.225, with a corresponding *F*-statistic of 385.0, clearly highly significant. The third-stage augmented gravity model using the single logistics index together with the first-stage variables explains 71 percent of the variability in bilateral trade. This result is almost identical to the corresponding one (specification 16) in table 4, where six logistics variables (including distance) are used to obtain an adjusted *R*-squared value of 0.716. Thus the single logistics index successfully replaces several separate logistics indicators.

[14] Defined as (maximum – average time) / (average time). Safety stock is proportional to the standard deviation of forecast error over the lead time (see Bonini, Hausman, and Bierman 1997).

[15] The logistics index is equal to the in-sample predictions of the second-stage regression or, equivalently, the weighted average of the second-stage coefficients multiplied by the values of the corresponding variables.

Table 5. Three-stage Logistics Index Estimation

Variable	First stage	Second stage	Third stage
	Dep. variable first and third stages: Log of bilateral exports Dep. variable second stage: First-stage residuals		
Log of exporter's GDP	1.200 (61.67)		1.285 (76.1)
Log of importer's GDP	0.888 (46.04)		0.925 (55.55)
Exporter's Corruption Perception Index	0.298 (24.09)		0.253 (22.86)
Importer's Corruption Perception Index	0.252 (17.85)		0.164 (12.5)
Regional trade agreement dummy variable	1.005 (11.5)		0.346 (4.87)
Log of distance		-1.307 (-34.61)	
Total time (freight plus ports)		-0.007 (-3.74)	
Coefficient of variation for total time		-0.947 (-4.56)	
Log of total processing cost		-0.232 (-6.02)	
Logistics index			1.083 (41.13)
K	6	5	7
R-squared	0.620	0.226	0.713
Adjusted *R*-squared	0.620	0.225	0.713
Observations	5149	5149	5149
F-statistic	1710.0	385.0	2317.0

Note: Dependent variable for first and third stages is total bilateral exports (in logs) in 2003 or latest year available. Dependent variable for second stage is first-stage residuals. Corruption Perception Index is for 2004, from Transparency International. Figures in parentheses are *t*-statistics (based on robust standard errors). Constant terms are not shown.
Source: Authors' calculations.

Implications for Logistics Improvements

The gravity model with the logistics index can be used to evaluate the effectiveness of initiatives to improve logistics and to help guide the allocation of resources to and deployment of such initiatives. This section describes how this can be done, with some illustrative examples.

Government agencies and the private sector in a country can collaborate to improve indicators of logistics performance linked to the logistics index. Of course, the distance between two countries cannot be changed. But since the distance measure is used as a surrogate for freight costs, improvement in this measure can be interpreted as efforts to reduce the freight rate (such as dollars per kilometer) for bilateral trade. Freight costs could be reduced by, for example, deregulating transportation, expanding ports to increase capacity, and promoting the growth of the third-party logistics industry to allow more consolidation of cargo flows. Trade-related processing time and cost can be improved by reengineering processes to eliminate unnecessary steps and streamline others (such as by introducing more parallel processing rather than sequential processing), introducing advanced information technologies (such as electronic customs clearance and documentation flows), using data mining and screening methods to identify only high-risk containers for security inspections, and adopting advanced scanning technologies to shorten cargo inspection times. The development of logistics parks—such as the Suzhou Park in China, which includes free trade zones with special transport routes to ports and streamlined customs processes—can also help reduce time and cost. All these improvements can also help reduce bottlenecks in the process and eliminate unnecessary waiting times and therefore reduce the variation in the processing time.

Let:

$S(i,j)$ = Value of bilateral trade from country i to country j;

$L(i,j)$ = Logistics index from country i to country j;

$d(i,j)$ = Distance from country i to country j;

$T(i,j)$ = Average total time (transport and trade-related processing) from country i to country j;

$\sigma(i,j)$ = Standard deviation of total time from country i to country j;

$C(i,j)$ = Total processing cost from country i to country j;

In the rest of the section, the (i,j) term in the variables is suppressed without loss of generality. From stage 2 of the gravity model (see table 5), the logistics index can be represented as:

$$L = -1.307(\ln d) - 0.007T - 0.947(\sigma/T) - 0.232(\ln C).$$

From stage 3, it can be seen that:

$$\ln S = K' + 1.083L$$

$$= K' - 1.4159(\ln d) - 0.0073T - 1.0258(\sigma/T) - 0.2508(\ln C),$$

where K' is a constant representing all the terms of independent variables in stage 1. Thus it is possible to write:

$$S = Kd^{-1.4159} \exp(-0.0073T - 1.0258\frac{\sigma}{T})C^{-0.2508}, \quad (1)$$

where $K = \exp(K')$. It is easy to derive:

$$\frac{\partial S}{S} = -1.4159\frac{\partial d}{d}.$$

$$\frac{\partial S}{S} = -0.2508\frac{\partial C}{C}.$$

$$\frac{\partial S}{S} = -1.0258\frac{\sigma}{T}\frac{\partial \sigma}{\sigma}.$$

$$\frac{\partial S}{S} = \left(-0.0073T + 1.0258\frac{\sigma}{T}\right)\frac{\partial T}{T}.$$

Thus with a 1 percent reduction in the distance measure, bilateral trade could increase by 1.4159 percent. This is of course well known, as the coefficient in the log-form of the gravity model represents the elasticity of the variable. Similarly, a 1 percent reduction in the total trade-related processing cost could result in a 0.2508 percent increase in bilateral trade.

The effect of reducing the standard deviation of processing time is a function of the current coefficient of variation of processing time. The larger is the coefficient of variation, the larger is the impact of a 1 percent reduction in the standard deviation of processing time. Note that the impact of a 1 percent reduction in the average processing time would be proportional to the magnitude of the current average processing time. But that positive impact is lessened if there is a lot of variability in the processing time—that is, a large coefficient of variation of processing time. Hence, high variability in processing time would lead to reduced impact of improvements in processing time. Variability creates uncertainties, which lead to potentially higher safety stocks and service degradation. As a result, the positive impact from reducing processing times is not fully appreciated when the variability of processing time is high.

Some examples of bilateral trade flows help illustrate the effects of improvements in σ and *T*. Consider the bilateral trade flows from Brazil, China, and Pakistan to the United States and the United Kingdom (table 6). These illustrative examples show that when the coefficient of variation is between 0.273 and 0.353 and the total processing time between 58 and 70 days, the effect of a 1 percent improvement in σ is in the range of 0.2801–0.3621 percent and that of a 1 percent improvement in T in the range of 0.0733–0.2206 percent. Note that the higher is the coefficient of variation, the lower is the impact of a one percent improvement in the total processing time. In the case of trade from Pakistan to the UK, for example, the high variability of processing time results in very modest improvement in trade when processing time is improved (without reducing the variability).

Table 6. Illustrative Example of Impacts of Logistics Improvements on Bilateral Trade

	Value of T (days)	**Value of σ/T**	**Elasticity of σ $(\partial S/\partial\sigma)/(S/\sigma)$**	**Elasticity of T $(\partial S/\partial T)/(S/T)$**
Brazil to US	59.7	0.285	-0.2924	-0.1445
China to US	58.5	0.273	-0.2801	-0.1480
Pakistan to US	61.9	0.291	-0.2985	-0.1544
Brazil to UK	70.1	0.285	-0.2924	-0.2206
China to UK	60.3	0.315	-0.3231	-0.1181
Pakistan to UK	59.5	0.353	-0.3621	-0.0733

Note: The two columns on the right hand side of the table shows the effect of a 1 percent reduction in the logistics variables σ and T.
Source: Authors' calculations.

Most of the second derivatives are positive; the only one with an unclear sign is $\partial^2 S/\partial T^2$. But for reasonably large T values, such as 30–100 days, this second derivative is also positive. The S function is convex in the four variables that make up the logistics index. If d is replaced by $d - \Delta d$, C by $C - \Delta C$, T by $T - \Delta T$, and σ by $\sigma - \Delta\sigma$, where all the deltas represent decision variables on the magnitudes of logistics improvements, the S function is a concave function of the delta variables. Let w_d, w_C, w_T, and w_σ be the respective cost per unit of improvements in d, C, T, and σ. Suppose there is a total budget of B to spend on logistics improvements. Then:

$$w_d\Delta d + w_C\Delta C + w_T\Delta T + w_\sigma\Delta\sigma = B. \qquad (2)$$

An optimal solution to the well-defined nonlinear optimization problem of maximizing (1) subject to (2) would produce the optimal allocation of resources across the possible logistics improvements.

The analysis above assumes that σ is independent of T. In reality, it is possible that σ is a function of T; indeed, it is likely that σ is an increasing function of T. If so, the explicit relationship between the two needs to be defined, and the impact of these variables on S would have to be modified accordingly. For example, one common relationship between σ and T is $\sigma^2 = a^2T$, where a is a parameter representing some variability measure. Under this assumption:

$$\frac{\partial S}{S} = -1.0258\frac{\sigma}{T}\frac{\partial a}{a} = -1.0258\frac{a}{\sqrt{T}}\frac{\partial a}{a},$$

$$\frac{\partial S}{S} = \left(-0.0073T + 0.5129\frac{a}{\sqrt{T}}\right)\frac{\partial T}{T}.$$

Finally, many projects to improve logistics are not specific to a particular bilateral flow. For example, investing in information technologies to improve customs clearance processes for an exporting country can benefit all outbound flows. In that case the evaluation of the impacts of such projects should be based on aggregate bilateral trade flows.

Conclusions

Past research into determinants of international trade highlighted the importance of the basic gravity model augmented by additional variables representing sources of friction. Studies modeled these sources of friction using various proxies, including indices based on expert judgment in some cases. This paper focuses on logistics friction and draws on an extensive data set recently compiled by the World Bank. It also updates past studies by using bilateral trade data for 2003 (or the most recent data available).

After including model variables associated with earlier studies, the analysis finds that new variables directly related to logistics performance have a statistically significant relationship with the level of bilateral trade. It also finds that a single logistics index can capture virtually all the explanatory power of several logistics indicators used together. A single logistics index is simple to evaluate and allows easy benchmarking. In addition, it can be used to help direct resources to their most effective uses when there are competing initiatives to improve a country's logistics operations.

The findings should spur organizations that have direct or indirect power over logistics performance in port operations to focus attention on reducing sources of logistics friction as a way to increase their country's ability to compete in today's global economy.

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Appendix

Table A.1. Economies in Bilateral Trade Analysis

Albania	Korea, Rep. of
Algeria	Lebanon
Angola	Lithuania
Argentina	Madagascar
Australia	Malaysia
Bangladesh	Mexico
Botswana	Mongolia
Brazil	Mozambique
Bulgaria	Namibia
Burkina Faso	Nepal
Cambodia	Nicaragua
Cameroon	Nigeria
Canada	Norway
Chile	Oman
China	Pakistan
Colombia	Peru
Costa Rica	Philippines
Côte d'Ivoire	Poland
Dominican Republic	Portugal
Ecuador	Romania
Egypt, Arab Rep. of	Russian Federation
El Salvador	Rwanda
Estonia	Saudi Arabia
Finland	Sierra Leone
France	South Africa
Georgia	Spain
Germany	Sri Lanka
Ghana	Sweden
Honduras	Switzerland
Hong Kong, China	Taiwan, China
Hungary	Tanzania
India	Thailand
Indonesia	Turkey
Iran, Islamic Rep. of	Ukraine
Ireland	United Kingdom
Italy	United States
Japan	Vietnam
Jordan	Yemen
Kazakhstan	Zambia
Kenya	Zimbabwe

Total: 80