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Diffusion of Containerization

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Abstract

This paper uses a newly constructed, comprehensive dataset to investigate the diffusion of containerization. The data show that country adoption is exceptionally fast while firm usage increases more slowly. To guide my empirical investigation, I build a multi-country trade model with endogenous adoption of a new transportation technology that is consistent with these facts. I then test empirically the predictions of the model and find that: (1) usage of containerization increases with firms' fixed costs and the size and average income of the container network; and (2) adoption depends on expected future usage, adoption costs, and trade with the United States, the first and largest user of containerization.

Keywords: globalization, transportation, trade, technology diffusion

JEL-Classification: F63, L91, N70, O33

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I Introduction

The ubiquitous shipping container is the most visible piece of a complex intermodal system called containerization, which also includes trucks, trains, container ships, specialized cranes, and storage facilities. Containerization is at the center of today's web of global supply chains, allowing the swift movement of goods across the world.[1] "[W]ithout [the container], the tremendous expansion of world trade in the last forty years—the fastest growth in any major economic activity ever recorded—could not possibly have taken place" (Drucker (2007), p. 28).

Despite its pervasive presence, containerization is a fairly recent technology; it was first used in 1956. However, by 1977, 68 countries had already adopted the technology. The diffusion was exceptionally rapid, especially when compared with other transportation technologies. For example, Comin and Hobijn (2010) estimate that it took freight railways 79 years, cars 44 years, freight aviation 42 years, and trucks 35 years, before they reached half of the countries in their sample—it took containerization only 20 years. Why was containerization's diffusion so fast, considering that it was also an "almost indescribably expensive revolution in transportation"?[2]

This paper uses a unique newly constructed dataset to investigate the diffusion of containerization from two complementary perspectives, adoption and usage. The dataset consists of information on worldwide adoption of container-port infrastructure and usage of containerization at 684 ports for the entire history of containerization (from the inaugural container journey in 1956 up to the present). Two stylized facts emerge from the data: (1) The adoption of containerization, which follows an S-shaped pattern, is exceptionally fast,[3] and (2) conditional on adoption, usage of containerization in international trade increases much more slowly than adoption.[4]

To understand the diffusion of containerization and guide my empirical investigation, I build a multi-country trade model that is consistent with these facts and allows endogenous adoption of a new transportation technology by both firms and countries. The model adopts a monopolistic competition framework in the spirit of Melitz (2003) in

[1] According to the United Nations Conference on Trade and Development, containerized trade "accounted for 65 percent of 'other dry cargo' in 2012 (that is, nearly two thirds of the 2.28 billion tons of dry cargo that remain after removing dry-bulk commodities)" (UNCTAD (2013)).

[2] Containerization requires an exceptionally large initial capital outlay (in containers, chassis, forklifts, ships, cranes, and waterfront space), a significant obstacle to adoption (see Kendall (1986)).

[3] This S-shaped pattern of adoption is in line with the large literature on technology diffusion (Griliches (1957), Mansfield (1961), Gort and Klepper (1982), and Skinner and Staiger (2005)).

[4] Usage of containerization took off only after half of the countries in my sample had already built at least one container port.

which heterogeneous exporting firms choose between two transportation technologies: in my context, containerization and breakbulk.[5] Containerization involves lower transportation costs than breakbulk shipping, but it requires a higher fixed cost. In addition, each country's transportation sector decides whether or not to construct a container port, an infrastructure that is necessary for firms to be able to use containerized shipping. Starting out with the decline in containerization's fixed costs over time, the model delivers an aggregate diffusion pattern consistent with the data.[6] International trade is crucial in the diffusion of containerization: While the first adopters have large enough domestic trade to be able to adopt containerization straightaway, adoption by other countries arises as a result of network effects.

The model delivers country-level predictions that I test empirically using the data that I collected. My empirical strategy consists of a two-step estimation: I first estimate usage of containerization in a country-year panel and then use that estimate of containerized trade in an hazard model of adoption. I find that usage of containerization increases with the length of the domestic rail network and the trade-weighted average size and income of the container network. In addition, these three factors have a larger impact on usage of containerization in low to medium-low income countries than in high to high-income countries. With regard to adoption, I find that expected future usage of containerization, real income per capita, and trade with the United States, the first and largest user of containerized shipping, increase the likelihood of adoption.

My paper contributes to two literatures, those concerned with international trade and technology diffusion. Among the international trade literature, my paper is especially relevant to research concerned with barriers to international trade, particularly international transportation. Several papers have documented how technological improvements during the period 1870–1914 have reduced shipping costs (North (1958, 1968) and Mohammed and Williamson (2004)), and others have identified a link between these technology-driven declines in shipping costs and growth in trade (Estevadeordal et al. (2003) and O'Rourke and Williamson (2001)). In contrast, for the post-World War II period, Hummels (2007) finds no evidence of a decline in shipping costs—instead, they were little changed from 1952 to 1970 and increased substantially from 1970 through the mid-1980s. Even taking into account the sharp increases in fuel costs in the 1970s, these findings are surprising,

[5] Breakbulk refers to transporting goods in the ship's hold, packed in cartons, bags, bales, or pallets, instead of in shipping containers.

[6] The fixed cost of containerization declines for several reasons: (1) standardization, (2) the development of leasing companies, (3) the development of less-than-container load (LCL) services, (4) reductions in the cost of logistics services as a result of learning and competition between suppliers, and (5) the development of complementary technologies (see Section III for more detail).

especially in light of the rise in trade since 1950.[7] Moreover, despite the large rise in fuel costs for part of the period and no evidence of a decline in shipping costs, containerized trade increased strikingly at an average rate of between 8 and 9.6 percent per year, measured in tonnage and twenty-foot-equivalent units (TEUs), respectively.[8] Clearly, understanding containerization's diffusion is crucial for making sense of the growth in trade in the post-World War II period. This paper makes a contribution to this literature by identifying the forces behind the diffusion of containerization across countries and over time. In addition, by highlighting the role of the trade network in the diffusion of containerization, it suggests that future research using the standard gravity model of trade should take into consideration the impact of the trade network.

By constructing and analyzing extensive cross-country data for the diffusion of a new technology, this paper contributes to the recent empirical literature on technology diffusion at the international level (Comin and Hobijn (2004, 2010)).[9] While this literature has emphasized the role of cross-country income differences in explaining lags in international technology adoption, my work reveals that trade linkages are an important determinant of international technology diffusion over and above lags in per-capita income.[10] This paper also adds to a long-standing empirical literature on technology diffusion that has focused on the extensive margin of adoption, i.e., the spread of a new technology across potential adopters (Griliches (1957), Mansfield (1961), Gort and Klepper (1982), and Skinner and Staiger (2005)), as well as more recent papers that have gone beyond the first use of a new technology and have considered the intensive margin, i.e., the level of technology usage by its adopters (Battisti and Stoneman (2003), Battisti and Stoneman (2005), and Comin et al. (2008)). My paper connects these two complementary perspectives of technology diffusion to provide an overall picture.[11]

Containerization transformed the entire economics of shipping and became an essential

[7] World trade, defined as the sum of real imports and exports, expanded by a factor of 36.5 from 1950 to 2008, which corresponds to an average rate of 6.4 percent per year (sources: IMF (2002a), IMF (2013), and FRED series CPIAUCNS).

[8] Source: Author's dataset.

[9] Stoneman and Battisti (2010) point to lack of data as the main reason for the paucity of international studies of technology diffusion.

[10] Several low and medium-low income countries that had significant trade linkages with the initial adopters of containerization adopted the technology before 1971.

[11] My work also contributes to a growing literature on estimating the effects of networks on technology diffusion, including recent studies that focus on geographical patterns (Saloner and Shepard (1995), Goolsbee and Klenow (2002), Gowrisankaran and Stavins (2004), and Bogart (2007)). This empirical literature complements a well-established theoretical literature on technology adoption in the presence of network externalities (Katz and Shapiro (1985, 1986); Farrell and Saloner (1985, 1986); and Cabral (1990)).

piece of today's globalized world.[12] This paper offers new perspectives into the international diffusion of new technologies that change the way international trade works and how the global economy is linked together. My conclusions show that it is important to understand how the inland transportation network interacts with the maritime system to make these new technological advances available across the global trade network. In addition, this paper shows that the relationships within the existing trade network play a crucial role in the international diffusion of new transportation technologies, with significant consequences to the future scale and performance of international trade.

The remainder of the paper is structured as follows. Section II describes the dataset that I have constructed and the diffusion pattern observed in the data. Section III presents a model that is consistent with the data and the model's testable results. Section IV consists of my empirical analysis. Section V concludes.

II New Data on Adoption and Usage of Containerization

In order to investigate the diffusion of containerization, I have assembled historical data on the adoption and usage of this technology from the inaugural container journey in 1956 up to the present. In particular, my dataset contains information for all general cargo ports on the initial adoption decision (defined as the year when the first container port is constructed) and the share of trade that is containerized.[13] Since ports are the primary nodes of the world shipping network and maritime shipping is the dominant mode of transportation for global trade, I concentrate on traffic passing through ports, omitting that which passes through inland depots.[14] In order to extend my dataset further, however, I include river as well as sea ports.

The three main sources of data are *Containerisation International Yearbook*, *Shipping Statistics Yearbook*, and *Lloyd's Ports of the World*. All three are annual publications of the container and shipping industries, available only in book format for most of the period.

[12]In 2002, the IMF's *World Economic Outlook* called "the introduction of containers for sea transport [one of] the most important technological breakthroughs of the past fifty years" (IMF 2002b, p. 116).

[13]General cargo ports are ports that handle any type of "dry cargo," excluding "dry-bulk commodities." This comprises a large variety of goods, including both manufactured and semimanufactured goods, but it does not include goods such as oil, fertilizers, ore, and grain. The shipping industry considers all general cargo trade to be containerizable, so it can be shipped either in containers or breakbulk (see Institute of Shipping Economics and Logistics (2008) and U.S. Department of Transportation (2008)).

[14]Despite the recent growth in air transport, maritime shipping accounted for 75 percent of world trade by volume in 2006 (Mandryk (2009)) and the majority of world trade by weight (Hummels (2007)).

I also collected data from port websites and requested data directly from port authorities. For most ports in my dataset, container tonnage data starts after 1969, since before then containerized trade was reported together with all general cargo trade (Pacific Maritime Association (1996)).[15] My final dataset consists of the adoption year for 145 countries and data on containerized and general cargo trade for 684 ports in 127 countries. See Appendix A for detailed information about data sources, coding rules, country coverage, and adoption years.

Figure I depicts the two components of the diffusion of containerization—adoption and usage—over the period 1956–2008. The solid line is the share of countries that have adopted containerization (i.e., they have at least one container port), the dashed line is the share of ports that have adopted containerization (i.e., they have built container-handling infrastructure), and the dash-dotted line is the share of containerized trade (i.e., the fraction of general cargo trade that is containerized). Two stylized facts emerge from the observed pattern of diffusion. First, adoption, which follows an S-shaped pattern, is exceptionally fast: by 1983, almost 90 percent of the countries had adopted containerization. Moreover, the slower pace of port-level adoption relative to country-level adoption highlights the interconnection between containerization and international trade. Containerization diffused first across countries, as each country built the first container port in order to join the network. With the exception of the U.S. and Australia, two large countries which built several container ports very early on to serve their domestic containerized trade, other countries viewed the container port primarily as a gateway to using containerization for international trade. Therefore, it was only after about half of the countries had adopted the technology that the number of additional container ports greatly increased. Second, conditional on adoption, usage of containerization in international trade increases much more slowly over the period. That firms did not adopt the new shipping technology right away, after the container port was built, suggests that they faced a fixed cost for using containerization.

Two sets of events influenced the diffusion of containerization over the period, and we can see their mark in these diffusion curves. First, the international standard for containers was approved in 1967, after six years of discussions and negotiations. Setting the standard meant that containers could become entirely intermodal. Until this point, containerization had been adopted exclusively in the United States and Australia, was used for domestic trade only, and consisted of incompatible container boxes, each adjusted

[15] For a few small ports, trade data is patchy and scarce over the period. I therefore exclude these ports from the final dataset. Nevertheless, since these ports handle very small trade volumes, their omission is likely to cause only a very small bias in my measure of containerized trade at the country level.

to the characteristics of container shipping companies' specific markets. Starting in 1966, containerization became an international shipping technology—transatlantic container services started to connect the U.S. east coast and Europe. As we see in Figure I, this is when adoption took off. The second set of events includes the expansion of container leasing after the 1970s and the development of LCL services in the 1980s.[16] Together with standardization, they contributed to the reduction in containerization's fixed cost, which stimulated container usage. Accordingly, Figure I shows usage of containerization increasing slowly during the 1970s and accelerating after the late-1970s.

Figures II through IV display the geographical diffusion of containerization.[17] From its inception in 1956—when Malcolm McLean sent a converted World War II tanker filled with 58 truck trailers from Newark, NJ to Houston, TX—until 1965, containerization was used only for domestic shipping within the U.S. and Australia.[18] But, within five years after approval of the international standard, most countries in Western Europe adopted the new technology. These initial adopters had both high income and large shares of world trade, particularly due to significant trade linkages among themselves and with the United States. However, there were also several low and medium-low income countries among the early adopters: Colombia, Ecuador, India, Ivory Coast, Nigeria, Peru, and the Philippines adopted containerization before 1971.[19] That all these countries had significant trade linkages with the initial adopters—notably the United States, the United Kingdom, Japan, Germany, and France—suggests that the trade network is an important determinant of diffusion over and above per-capita income.[20] Containerization diffused through all parts of the world during the 1970s and 1980s, as we can see in Figure IV. In fact, by 1983, almost 90 percent of the countries had constructed at least one container port. From this point onwards, the network grew in density as more container ports were constructed. In 2008, only seven countries in my dataset had yet to adopt containerization: Albania, Cabo Verde, Gabon, Solomon Islands, Somalia, and São Tomé e Principe.

[16]Sources: National Magazine Co. (1983), National Magazine Co. (2009), and Kele (2011).

[17]For the complete diffusion, see slideshow at www.giselarua.com/diffusion-of-containerization.html.

[18]These countries had in common two important characteristics: high labor costs and a domestic maritime industry that was protected from foreign competition.

[19]This income classification is in accordance with the World Bank definitions prior to 1990. See Appendix A for the entire list of adoption years for all countries in my dataset.

[20]The importance of the trade network is also clear when looking at the trade-weighted average number of adopters at the year when a country adopted containerization. Figure C.1 in the appendix shows that (1) except for the initial adopters, the majority of countries adopted containerization when over 60 percent of their trade partners had already adopted and (2) the distribution of network size at the year of adoption gradually shifted to the right-shift.

III Theoretical Framework

In this section, I develop a multi-country trade model that is consistent with the data and the above-mentioned role of firms' fixed costs and network effects on the diffusion of containerization. The purpose of the model is to discipline my empirical investigation and generate a set of hypotheses to be tested econometrically. The model has three main features: (1) monopolistic competition and heterogeneous firms in the production of goods, in the spirit of Melitz (2003); (2) endogenous firm choice between two transportation technologies, containerization and breakbulk; and (3) endogenous adoption of container-port infrastructure by a transportation sector.[21]

Model setup: I consider a world economy with M countries, indexed by $i = 1, 2, \ldots, M$. Each country has a measure one of firms, each producing a different variety. Varieties produced by country i's firms are different than those produced by country j's firms, so there is a measure M of varieties in the world. Let $\Omega_{i,t} \in M$ be the mass of varieties available in country i at period t. The preferences of a representative consumer in country i at period t are given by a constant elasticity of substitution (C.E.S.) utility function over a continuum of varieties indexed by k,

$$U_{i,t} = \left[\int_{k \in \Omega_{i,t}} \left(x_{i,t}^k \right)^{\frac{\epsilon-1}{\epsilon}} dk \right]^{\frac{\epsilon}{\epsilon-1}} , \tag{1}$$

where $x_{j,t}^k$ is consumption in country i of variety k at period t and the elasticity of substitution between varieties, $\epsilon > 1$, is the same in every country. Each consumer in country i owns all firms in the country and receives a share Y of their profits.

At each period t, the demand for variety k that results from consumers' utility maximization (subject to their budget constraint) is

$$x_{i,t}^k = \left(\tilde{p}_{i,t}^k \right)^{-\epsilon} P_{i,t}{}^{\epsilon-1} Y_{i,t} , \tag{2}$$

where $\tilde{p}_{i,t}^k$ is the consumer price of variety k in country i, which includes transportation costs if variety k is imported. $P_{i,t}$ is the standard aggregate C.E.S. consumer price index, $P_{i,t} = \left[\int_{k \in \Omega_{i,t}} (\tilde{p}_{i,t}^k)^{1-\epsilon} dk \right]^{\frac{1}{1-\epsilon}}$.

To produce one unit of output, firms use an optimal combination of inputs costing

[21]The first two features of my model are akin to other papers that have added additional choice to the standard Melitz model, for example Helpman et al. (2004).

a. Factor prices are normalized to one, and the parameter a is a firm-specific measure of the inputs that need to be used to produce one unit of output. Its inverse is the firm's productivity and is distributed according to the cumulative distribution function $G(a)$. This distribution is the same in every country and over time.

Consider a firm in country j that wants to export to country i. In addition to production costs, it faces two additional exporting costs: an "iceberg" shipping cost $(\tau_{ij} - 1)$ and a fixed cost f_j. These costs are the same for all firms in the country and are zero if a firm sells in the domestic market.[22] Assume also that shipping costs are symmetric, i.e., $\tau_{ij} = \tau_{ji}\ \forall i \neq j$. An exporting firm can choose between two shipping technologies: containerization and traditional breakbulk. A smaller amount of goods "melts away" during containerized shipping than breakbulk shipping, so that $1 < \tau_{ij}^c < \tau_{ij}^b$.[23,24] However, the fixed cost of exporting using containerization is initially higher than the fixed cost of exporting in breakbulk, $f_{j,t}^c > f_j^b$.[25] This is because, in the initial period of the "container revolution," firms that wanted to use containerization had to keep sophisticated distribution, logistics, and inventory management systems that were more costly than their traditional systems, which had been created for working with breakbulk shipping.[26]

[22]Assuming zero fixed costs if a firm sells in the domestic market ensures that firms will always sell domestically (operating profits from selling in the domestic market are always positive). This way, I can ignore domestic profits hereafter and focus only on profits obtained from sales in the foreign market.

[23]Since container ships are larger and faster than conventional ships, containerization not only lowers sailing times, but also reduces the price per ton-mile shipped, as a result of economies of scale. (For example, a study by the Port of New York Authority in the 1960s estimated that shipping Ballentine beer from Newark to Miami would cost 4 dollars per ton with breakbulk, while it would only cost 25 cents per ton with containerization (Levinson 2008, p. 48). Furthermore, using *U.S. Imports of Merchandise* data for 1974–2004, Hummels (2007) finds evidence that exporters that containerize their trade face significantly lower shipping costs.) The parameter τ_{ij}^c also captures containerization's other advantages relative to breakbulk: As an intermodal system, it is dramatically faster than breakbulk; containers filled with goods can quickly move between warehouse, ship, train, and truck. Containerization is also more reliable; involves fewer contracts; permits a considerable reduction in loss, pilferage, and damage; and has lower insurance fees. Furthermore, containerization largely reduces the need for longshoremen, bringing substantial savings on wages—although not without strong opposition from longshoremen unions worldwide: "while six gangs of longshoremen would have taken 5 days to load and unload a conventional ship with approximately 10,000 tons of cargo in the 1950s, by 1974, five huge container cranes took less than 24 hours to load and unload a container ship with 15,000 tons of cargo" (O'Hara (1974)).

[24]We can think of these lost units as ship lines' compensation for transporting the goods. Modeling the costs of containerized shipping as "iceberg" is akin to assuming that ship lines determine freight rates based on the volume of goods transported. Although this is not very far from reality, it abstracts from other features of container freight rates such as load, weight, stowage factor, refrigeration, and route.

[25]Since there is no uncertainty in the model, these fixed costs can alternatively be thought of as the amortized per-period equivalent of a one-time sunk cost.

[26]Several factors contributed to these high fixed costs: First, exporting firms had to readjust their logistics systems to accommodate the use of ship-line-specific container boxes, which differed in size and in the mechanism of their corner fittings. For example, if a firm had contracted its containerized shipping with Sealand (which used 35-foot containers) but imported intermediate inputs from firms that

Several developments in the container industry have pushed down the fixed cost of containerized shipping: among others, the approval of an international standard for containers, the spread of both container leasing and LCL services, the price effects of learning and competition between suppliers of logistics services, and complementary innovations like barcode scanning and computerized logistics.[27] For breakbulk, a shipping technology that has been around for millennia and has predominately relied on human muscle, the cost declines—often associated with improvements in forklift truck technology—have been much smaller.[28] In the model, these larger fixed cost declines for containerization, relative to breakbulk, translate into a decreasing fixed cost of containerization ($f^c_{j,t+1} < f^c_{j,t}\ \forall t$) and a constant fixed cost of breakbulk shipping ($f^b_{j,t+1} = f^b_{j,t}\ \forall t$).

The choice between containerization and breakbulk shipping is available to all firms since they all produce varieties that are containerizable. However, it is only available in country pairs where both countries have adopted containerization, i.e., they both have ports with container handling infrastructure and equipment.[29] If this port infrastructure does not exist, firms can only use breakbulk shipping.

In each country, the transportation sector is responsible for building, maintaining, and operating the maritime transport system. For simplicity, I assume that it consists of only

worked with Matson (which used 24-foot containers), it could not interchange the containers and therefore incurred high fixed costs for managing these differently sized boxes. Moreover, firms could rack up still more costs from delays in ship lines providing them with empty containers. During the first decade of containerization, a major user of containers complained that he had to return "empties" to the ship line within a short period of time but would then be waiting a day or longer for the same ship line to bring him an empty container in which he could pack his next outbound shipment: "Sometimes my returning 'empty' passes the incoming container, which also is empty. It's a very wasteful and extravagant way of doing business" (Kendall 1986, p. 233). A second factor contributing to the high initial fixed costs of containerization was that container carriers only offered full container service, while many firms needed to carry smaller volumes. Small- and medium-sized manufacturing firms wanting to use containerization had no choice but to maintain sophisticated distribution and inventory management systems in order to consolidate production to fill a container load. It was not until the 1980s that container carriers started to offer a limited number of LCL services, and even then, these services were not only infrequent but also extremely expensive (Kele (2011)).

[27] The impact of learning and competition between suppliers on the price of a technology has been amply documented in the literature on technology diffusion (Geroski (2000) and David and Olsen (1992)). Moreover, these price effects were likely bolstered by usage of containerization in U.S. military operations during the Vietnam War and the military escalation of the Cold War.

[28] As Levinson points out, given the different sizes and nature of goods shipped in breakbulk, human muscle was often the ultimate solution, even with sophisticated forklift trucks readily accessible (Levinson 2008, p. 18).

[29] "Containerization required shore facilities totally different in nature and appearance from those that had served for a century or more during the supremacy of the conventional passenger ship and cargo-liner" (Broeze 2002, p. 165). These special shore facilities include, among others, specialized cargo-handling equipment, ample quayside space, deep water access, and facilities for truck and rail inland movement (see Broeze 2002, pp. 165–211, for details).

one port. There is no trade by land, and all trade needs to pass through the port. There is also only direct shipping between countries.

The transportation sector charges a usage fee, $0 \leq \phi < 1$, per unit of trade that passes through the port. This fee is strictly positive for a container port and zero for a traditional breakbulk port. Therefore, for one unit of containerized goods from country j to arrive in country i, firms in country j have to ship $\tilde{\tau}_{ij}^c = \tau_{ij}^c/[(1-\phi_j)(1-\phi_i)]$ units (they pay usage fees at both origin and destination ports). Although the transportation sector is private, the public-utility nature of port infrastructure gives rise to some public control and regulation. In fact, many ports operate under long-term concessions by local or national authorities, and new construction projects often involve government appropriations.[30] I incorporate this public-private duality into the model in two ways: First, the transportation sector's objective when building a container port is to break-even, not to maximize profit. Second, the usage fee is constrained by regulation.

Optimal shipping technology: The optimal operating profits of a firm in country j with input parameter a from selling to consumers in country i are (see derivation in Appendix B1):[31]

$$\pi_{ij,t}(a) = (1-\alpha)\left(\frac{a\tau_{ij}}{\alpha P_{i,t}}\right)^{1-\epsilon} Y_{i,t} - f_{j,t} \ , \tag{3}$$

where $\alpha = (\epsilon - 1)/\epsilon$.

Define $(a_{ij,t}^c)^{1-\epsilon}$ as the productivity cutoff at which the operating profits from exporting using breakbulk are the same as the operating profits from exporting using containerization. In appendix B2, I show that this cutoff is

$$(a_{ij,t}^c)^{1-\epsilon} = \frac{f_{j,t}^c - f_j^b}{(\tilde{\tau}_{ij}^c)^{1-\epsilon} - (\tau_{ij}^b)^{1-\epsilon}} \frac{\alpha^{1-\epsilon}}{1-\alpha} \frac{P_{i,t}^{1-\epsilon}}{Y_{i,t}} \ . \tag{4}$$

Define also $(a_{ij,t}^b)^{1-\epsilon}$ as the productivity cutoff at which profits from exporting using

[30] For example, in his discussion of the impact of containerization on port systems, Broeze notes that while containerization's bolstering of port rivalry meant that "ports had to be able operate profitably," that "did not mean that local or national authorities did not occasionally provide financial and other support" (Broeze 2002, p. 165). Levinson makes a similar point: "Government investment in ports had been crucial to the development of container shipping in the 1960s and 1970s. With the exceptions of Felixstowe and Hong Kong, every major containerport in that era was developed at public risk and expense" (Levinson 2008, p. 238).

[31] Since each firm can be identified by both its variety and its productivity parameter, I will drop the k superscripts from now on.

breakbulk are zero. In the same appendix, I show that this cutoff is

$$(a^b_{ij,t})^{1-\epsilon} = \frac{f^b_j}{(\tau^b_{ij})^{1-\epsilon}} \frac{\alpha^{1-\epsilon}}{1-\alpha} \frac{P^{1-\epsilon}_{i,t}}{Y_{i,t}} \ . \tag{5}$$

To have some exporters using breakbulk, I assume that parameters are such that $(a^c_{ij,t})^{1-\epsilon} > (a^b_{ij,t})^{1-\epsilon}$: There are productivity levels at which exporters have positive profits from using breakbulk that are higher than the profits from containerization.[32] In equilibrium, firms choose only one of the shipping technologies but not both.

Conditional on the existence of a container port in both countries i and j at period t, which our atomistic firms take as given, the choice of transportation technology is determined by the cutoff level $a^c_{ij,t}$. Firms with productivity levels between $(a^b_{ij,t})^{1-\epsilon}$ and $(a^c_{ij,t})^{1-\epsilon}$ use breakbulk shipping, while only the most productive exporters, with productivity above $(a^c_{ij,t})^{1-\epsilon}$, find it profitable to use containerization. Figure V is a graphical representation of firms' decisions.[33]

To understand why the most productive exporters containerize and the others use breakbulk shipping, consider the difference in revenues and costs from shipping with both technologies (see Appendix B3 for derivations). The difference in firm revenues between shipping exports with containerization and shipping with breakbulk is

$$R^{(c-b)}_t = \left(\frac{a}{\alpha}\right)^{1-\epsilon} \left[(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}\right] P^{\epsilon-1}_{it} Y_{it} \ , \tag{6}$$

which is a positive and linear function of $a^{1-\epsilon}$. Likewise, the difference in firm costs between shipping with the two technologies is

$$C^{(c-b)}_t = (f^c_{j,t} - f^b_j) + a^{1-\epsilon}\alpha^{\epsilon} \left[(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}\right] P^{\epsilon-1}_{it} Y_{it} \ . \tag{7}$$

This cost difference is also a positive and linear function of $a^{1-\epsilon}$, but relative to the revenue difference, it has a larger intersection, $(f^c_{j,t} - f^b_j) > 0$, and a smaller slope.

Figure VI depicts these two differences as a function of the productivity index $a^{1-\epsilon}$. For the least productive exporters, a switch from breakbulk to containerization causes a larger cost increase than revenue increase. This is because, compared to breakbulk, containerization requires higher fixed costs relative to its savings in shipping costs. As a

[32]This is equivalent to assuming that the increase in containerization's fixed costs is high relative to the reduction in variable trade costs: $(\tilde{\tau}^c_{ij})^{\epsilon-1} f^c_{j,t} > (\tau^b_{ij})^{\epsilon-1} f^b_j \ \Leftrightarrow \ f^c_{j,t}/f^b_j > \left(\tilde{\tau}^c_{ij}/\tau^b_{ij}\right)^{1-\epsilon}$.

[33]Note that, since $a^{1-\epsilon}$ is monotonically increasing with firms' productivity $(1/a)$, we can think of it as a productivity index.

result, the least productive exporters choose breakbulk shipping.

In contrast, firms with higher productivity choose containerization. They export larger quantities (see proof in Appendix B3) and can therefore spread the fixed cost over a larger amount. As we can see in Figure VI, only firms with productivity above $(a^c)^{1-\epsilon}$ profit from exporting with containerization: The increase in revenues more than compensates for the increase in costs.

In addition, because the fixed cost of containerization is decreasing over time, the productivity cutoff is also decreasing.[34] The red line in Figure VI illustrates this point. The decline in the fixed cost allows some of the less productive exporters to profitably switch to containerization. Over time, further declines in containerization's fixed cost will cause an even higher number of exporters to containerize. In the limit, when the fixed cost of containerization is very low (such that $(a^c)^{1-\epsilon} > (a^b)^{1-\epsilon}$ stops holding), all exporters will have containerized.

Optimal adoption decision: In each country, the transportation sector faces a choice between keeping the traditional port infrastructure and building new port facilities adapted to containerization. In making this choice, the transportation sector takes other countries' adoption decisions as given (there is no strategic interaction between transportation sectors), as well as domestic and foreign firms' shipping choices. Adoption of containerization is an absorbing state; i.e., after the container port is constructed, it operates forever. Investment in containerization is irreversible.[35]

The transportation sector spends Γ_j units of the numeraire to build a container port in the following period. This includes all the financial, political, and social costs associated with adopting containerization.[36] In addition to the adoption cost, the transportation sector spends ω_j per unit of containerized trade to maintain and operate the container port.[37] Revenues come from the usage fee. When firms use the container port, they have

[34] While ship lines have undeniably invested in bigger and more efficient container ships, which arguably lowered shipping costs, modeling an additional decline in τ would only reinforce the effects of declining fixed costs.

[35] Empirically, this is true at the country level—no country in the sample went from adoption to non-adoption of containerization. Some ports in a given country have stopped providing container services, but they have always been replaced by other container ports in the same country.

[36] For example, "in the period between 1968 and 1973, shipowners, terminal operators, and port agencies in the United States alone invested seven and a half billion dollars in ships, containers, and port facilities" (Kendall 1986, pp. 217-218). In addition, a survey on the expenses involved in converting to containerization, published by the *The Journal of Commerce and Commercial* in 1977, estimated that acquiring container-handling cranes cost $1,75 million per 30-ton capacity and securing waterfront space for terminals and marshaling yards cost $250,000-300,000 per acre (Morison (1977)).

[37] For simplicity, I assume that Γ_j and ω_j are constant over time.

to pay a fee ϕ per unit of containerized goods that go through the port. For example, if country j builds a container port, the fee ϕ_j will be paid by all firms in country j that containerize their exports and all firms in country j's trade partners that containerize their exports into country j.

Each period, the total volume of containerized trade that goes through country j's port is denoted by $T^c_{j,t}$. As shown in equation (8), it is equivalent to the sum of all containerized exports and imports between country j and its trade partners that have adopted containerization before or in year t:

$$T^c_{j,t} = \sum_{l \neq j}^{M-1} A_{l,t} \left(m^c_{lj,t} + m^c_{jl,t} \right) \ , \tag{8}$$

where $m^c_{lj,t}$ are country j's containerized exports to country l, $m^c_{jl,t}$ are country j's containerized imports from country l, and $A_{l,t}$ is an indicator variable that equals one when country l has adopted containerization and zero when it has only a breakbulk port.

Accordingly, we can express the present discounted value of country j's expected profits from building a container port at t as

$$\Pi_{j,t} = \sum_{s=t+1}^{\infty} \rho^{(s-t)} \left[\left(\tilde{\phi}_j - \omega_j \right) E_{t-1} T^c_{j,s} \right] - \Gamma_j \ , \tag{9}$$

where $E_{t-1}T^c_{j,s}$ is country j's expected volume of containerized trade at period s, $s \geq t$, and the parameter ρ is the discount factor. For simplicity, I assume zero profits from operating a traditional breakbulk port. Given these expected profits from containerization, country j's optimal adoption decision is

$$A_{j,t} = \mathbf{1}\{\Pi_{j,t} > 0\} = \mathbf{1}\left\{ \left(\tilde{\phi}_j - \omega_j \right) \sum_{s=t+1}^{\infty} \rho^{(s-t)} E_{t-1} T^c_{j,s} > \Gamma_j \right\} \ . \tag{10}$$

The transportation sector chooses to adopt containerization at t if expected net revenues from adoption exceed the initial adoption cost. This, in turn, depends on whether domestic and foreign firms are expected to containerize enough trade over time for the transportation sector to break even.

Taking logs on both sides, the adoption condition inside the indicator function can be written in logarithmic form as

$$\ln\left(\tilde{\phi}_j - \omega_j\right) + \ln\left(\sum_{s=t+1}^{\infty} \rho^{(s-t)} E_{t-1} T^c_{j,s}\right) > \ln(\Gamma_j) \ . \tag{11}$$

Transportation sectors have complete information regarding domestic and foreign firms' shipping decisions, and they will use this information to estimate future levels of containerized trade.

Network effects and rapid diffusion: I assume that countries adopt containerization sequentially and decide whether or not to adopt based on the current state of the container network. In addition, to get the process started, I assume that there is at least one country in the world whose transportation sector makes positive profits from adoption of containerization even if no other country has adopted. This country is the United States; it was the first country to adopt containerization and used it for domestic trade only from 1956 to 1965.[38]

Smaller domestic markets and substantially high adoption costs preclude other countries from adopting immediately. Over time, firms' fixed cost of containerizing exports decline and expected containerized trade increases. As a result, countries' expected profits from adoption expand, and new countries adopt containerization. Since the decline in containerization's fixed cost affects firms' productivity cutoffs differently according to country (see equation (4)), countries will break even—and adopt containerization—at different points in time. The timing of adoption depends on how much the country trades with previous adopters, the magnitude of the shipping-cost gain from containerization, and differences in adoption costs.

Moreover, the structure of transportation sectors' adoption decisions implies the existence of network effects: When a country adopts containerization, the potential volume of containerized trade that other countries would have—if they adopt as well—increases.[39] This higher volume of containerized trade raises potential revenues and, as a result, the potential profits from adoption. The more countries that have adopted containerization, the stronger the incentive for others to follow. Therefore, network effects amplify the effect of countries' adoptions on each other and cause rapid diffusion.[40]

[38]I could, additionally, consider a second country, Australia, which adopted containerization in 1964 and also used it only for domestic trade until 1966.

[39]Since productivity is bounded, there might be a subset of countries with zero bilateral trade for which adoption by one country might have no effect on the expected volume of containerized trade.

[40]The diffusion pattern that results from this sequence of adoptions is S-shaped. Moreover, though

The model has a few limitations that are worth discussing. First, firms are differently affected by containerization only to the extent that there are productivity differences between them—containerization affects shipping costs of all firms in a given country equally, but only the most productive choose to use it. In reality, of course, the costs and benefits of containerization may vary across products. Some products are harder to accommodate inside "the box" because of their bulkiness or odd shape (e.g., Caterpillar equipment and machinery), fragile products need to be cushioned (e.g., electric light bulbs), some perishable goods need to be refrigerated (e.g., meats), and dangerous products take longer to pass security checks and clear customs. The handling and stowage characteristics of exported products matter for their unit transport cost, whether one thinks of this only in terms of the shipping cost or also in terms of time. To the extent that these differences are not captured by differences in productivity, they are not included in the model. Second, there are no intermediate goods. The model therefore does not address the role that location of different stages of production across the world has played in shaping today's global economy. Finally, in considering only direct shipping routes between countries, the model abstracts from the rise of international container hubs, such as Singapore and Hong Kong. Despite these shortcomings, the model presented here captures the main features of the diffusion of containerization that we observe in the data and provides a framework for the empirical analysis to which I turn next.

Predictions and estimating equations: In this section, I derive testable predictions for adoption and usage of containerization and obtain a two-step empirical specification that I use in the empirical analysis. I start with adoption.

Let $z_{j,t}$ be a latent variable defined as

$$z_{j,t} = \ln\left(\tilde{\phi}_j - \omega_j\right) + \ln\left(\tilde{T}^c_{j,t+1}\right) - \ln(\Gamma_j) \ , \tag{12}$$

where $\tilde{T}^c_{j,t+1} = \sum_{s=t+1}^{\infty} \rho^{(s-t)} E_{t-1} T^c_{j,s}$ is expected, present-discounted containerized trade. While financial, political, and social costs associated with adopting containerization are directly observable by decisionmakers, they are unobservable to the researcher. Assume, thus, that observable country characteristics that are associated with these adoption costs differ from the true data available to decisionmakers by an *i.i.d.* stochastic term μ^z, distributed independently of $z_{j,t}$, with a symmetric cumulative distribution $H(\mu^z)$. As a

multiple S-shaped adoption paths might result, we can generate a single S-shaped path of adoptions by assuming communication between countries, i.e., countries can credibly negotiate adoption with each other and adopt as soon as it is profitable.

result, country j's probability of adoption in year t given that it has not adopted before (the hazard function) can be expressed as

$$\begin{aligned}\Pr(A_{j,t}=1|A_{j,t-1}=0,\mathbf{X}) &= \Pr(z_{j,t}+\mu^z_{j,t}>0|z_{j,t-1}+\mu^z_{j,t-1}\leq 0,\mathbf{X}) \\ &= \frac{H(-z_{j,t})-H(-z_{j,t-1})}{1-H(-z_{j,t-1})}\ , \qquad (13)\end{aligned}$$

where $\mathbf{X}$ is a vector of observable variables.

In the empirical section, I estimate the logistic discrete-time hazard model implied by equation (13).[41] This model assumes that the conditional log odds that adoption occurs at year t, given that it did not occur before, is a linear function of observable variables, which I define as follows:

$$\ln\left(\frac{\lambda\left(t|\mathbf{X}\right)}{1-\lambda\left(t|\mathbf{X}\right)}\right)=\alpha_t+\beta_1\mathbf{y}_j+\beta_2\ln(\tilde{T}^c_{j,t+1})\ . \qquad (14)$$

The parameter α_t is the baseline hazard of country j adopting containerization in year t (when all observable variables are zero). To allow a more flexible estimation, I use a set of time dummies (instead of a linear specification, or even a polynomial or Weibull). Together, these time dummies identify the baseline hazard, while their individual coefficients allow for a different value of the logit hazard in each time period. $\mathbf{y}_j$ is a vector of country characteristics including log net port revenues ($\tilde{\phi}_j-\omega_j$) and log adoption costs (Γ_j), and $\tilde{T}^c_{j,t+1}$ is expected, present-discounted containerized trade.

Given that adoption depends on expected containerized trade, I now turn to firms' optimal decisions about which transportation technology to use to derive an estimating equation for containerized trade. I start by rewriting equation (8) as

$$T^c_{j,t}=\sum_{l\neq j}^{M-1}A_{l,t}\left(\frac{\tilde{\tau}^c_{lj}}{\alpha}\right)^{-\epsilon}\left[P^{\epsilon-1}_{l,t}Y_{l,t}\int_{a_L}^{a^c_{lj,t}}a^{1-\epsilon}\ dG(a)+P^{\epsilon-1}_{j,t}Y_{j,t}\int_{a_L}^{a^c_{jl,t}}a^{1-\epsilon}\ dG(a)\right]. \qquad (15)$$

Consistent with the literature and available evidence, assume that $G(a)$ is a Pareto distribution with shape parameter κ, $\kappa>\epsilon-1$, and support $[0,a_H]$ such that $G(a)=(a/a_H)^{\kappa}$. This implies that

$$\int_{a_L}^{a^c}a^{1-\epsilon}\ dG(a)=\frac{\kappa}{\kappa-\epsilon+1}\frac{(a^c)^{\kappa-\epsilon+1}}{a^{\kappa}_H}\ . \qquad (16)$$

[41] See Singer and Willett (2003) for a detailed discussion of the logit discrete-time hazard function.

In addition, since changes in containerized trade might be driven by changes in the scale of trade, I divide containerized trade by general cargo trade (i.e., containerizable trade). This way, my results will not be influenced by any sources of trade shifts that impact total trade: tariffs, trade agreements, exchange rate changes, currency unions, etc.[42]

Hence, containerized trade as a share of total general cargo trade, $ST^c_{j,t}$, is equivalent to (see derivation in Appendix B4)

$$ST^c_{j,t} = \frac{T^c_{j,t}}{T^{cb}_{j,t}} = \left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \frac{\sum_{l\neq j}^{M-1} A_{l,t} V^c_{lj,t}}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}} \ , \tag{17}$$

where

$$V^c_{lj,t} = (\tilde{\tau}^c_{lj})^{-\epsilon} \left[(\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon}\right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}} \left[P^\kappa_{l,t} Y^{\frac{\kappa}{\epsilon-1}}_{l,t} + \left(\frac{f^c_{l,t} - f^b_l}{f^c_{j,t} - f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y^{\frac{\kappa}{\epsilon-1}}_{j,t}\right] \tag{18}$$

and

$$V^{cb}_{lj,t} = (\tau^b_{lj})^{-\epsilon} (\tau^b_{lj})^{-\kappa+\epsilon-1} \left[P^\kappa_{l,t} Y^{\frac{\kappa}{\epsilon-1}}_{l,t} + \left(\frac{f^b_l}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y^{\frac{\kappa}{\epsilon-1}}_{j,t}\right] \ . \tag{19}$$

Thus, $ST^c_{j,t}$ is a function of the parameters of the model, such that

$$ST^c_{j,t} = F\left\{f^c_{j,t},\ f^b_j,\ Y_{j,t},\ (A_{l,t}, f^c_{l,t}, f^b_l, Y_{l,t}, \tilde{\tau}^c_{lj}, \tau^b_{lj},\ \forall l \neq j)\right\} \ . \tag{20}$$

I now use equations (14) and (17) through (20) to derive comparative static predictions which I then test in the empirical part.

Prediction 1. *A decline in the fixed cost of containerization, domestically and in the container network, increases the share of containerized trade.*

Proof. $\frac{\partial ST^c_{j,t}}{\partial f^c_{j,t}} < 0$ and $\frac{\partial ST^c_{l,t}}{\partial f^c_{l,t}} < 0,\ \forall l \neq j : A_{l,t} = 1$ (see Appendix B5). □

Intuitively, a decline in the fixed cost of containerization allows some of the less productive domestic exporters, with productivity that was previously too low, to switch to containerization. For the same reason, a decline in other countries' fixed costs allows some of their less productive exporters to use containerization when they export into our

[42] These sources of trade shifts have been extensively identified by the trade literature. See, for example, Frankel and Wei (1993), Eichengreen and Irwin (1995), Baier and Bergstrand (2001), Glick and Rose (2002), and Estevadeordal and Robertson (2004), among many others.

country. For testing this prediction empirically, I use the length of the domestic network of railway lines and paved roads as explanatory variables. These variables proxy for intermodal potential. While intermodal transfers significantly increase breakbulk logistics costs, because it is often necessary to change load units, they have a much smaller impact on containerization's logistics costs.[43] As a result, countries with higher potential for cost- and time-savings in transfers between land (rail and/or truck) and water transportation modes arguably face a smaller increase in fixed costs with containerization. These measures of intermodal potential are therefore inversely related to fixed costs, and for the first part of Prediction 1 to hold, their coefficients need to be positive: Countries with larger domestic land transportation networks use more containerized shipping. The second part of Prediction 1 refers to the container network. For testing the effect of changes in containerization's fixed costs of countries in the container network, I calculate the trade-weighted average length of other adopters' domestic networks of railway lines and paved roads—the network's average intermodal potential.[44] For this second part of Prediction 1 to hold, the coefficients of these network averages need to be positive.

Prediction 2. *An increase in the size of the container network (number of adopters) raises the share of containerized trade.*

Proof. $\frac{\partial ST^c_{j,t}}{\partial A_{l,t}} > 0 \; \forall l \neq j$ (see Appendix B5). □

The size of the container network corresponds to the number of trade partners that have adopted containerization. Analytically, this is equivalent to including more countries in the numerator of equation (17). Since $V^c_{lj,t}$ is always positive, expansions in the size of the container network increase containerized trade. I proxy network size with the trade-weighted average number of adopters in a country's trade network. In one specification, I also use the trade-weighted average number of container ports in the container network.

Prediction 3. *The impact of domestic and container-network income on the share of containerized trade is ambiguous.*

Proof. See Appendix B5. □

Since income is equivalent to spending in the model, an increase in domestic income causes domestic consumers to spend more, and imports increase. The share of additional imports that will be shipped in containers will depend on the relationship between fixed

[43]See Rodrigue et al. (2013) for details.
[44]The weights are average bilateral trade shares (in real dollars) over the previous five years.

and transportation costs of containerization and breakbulk across trade partners. Similarly, an increase in a trade partner's income generates higher imports into that country, which will be partially filled by our country's exports. In this case, the share of additional exports that will be shipped in containers will depend only on containerization's and breakbulk's transportation costs between our country and its trade partners. To estimate empirically the impact of domestic and container-network income on the share of containerized trade, I use log real gross domestic product (GDP) and the trade-weighted average of log real GDP in the container network as explanatory variables.

Prediction 4. *Higher containerization shipping costs decrease the share of containerized trade.*

Proof. $\frac{\partial ST^c_{j,t}}{\partial \tilde{\tau}^c_{lj}} < 0 \ \forall l \neq j$ (see Appendix B5). □

In the absence of internationally comparable freight rate data going as far back as the 1950s, I use the trade-weighted average maritime distance between our country and its trade partners as a proxy for containerization's shipping costs.[45] Because of economies of scale, I expect containerization's average shipping costs to decrease with distance. As Levinson notes, "a doubling of the distance cargo is shipped—from Hong Kong to Los Angeles, for example, rather than Tokyo to Los Angeles—raises (containerization's) shipping cost only 18 percent" (Levinson 2008, pp. 268–269). Therefore, for Prediction 4 to hold, the coefficient of the average maritime distance to the trade network needs to be positive.

Prediction 5. *The likelihood of adoption increases with expected future usage of containerization.*

Proof. Given the adoption condition (11), the coefficient β_2 in equation (14) is expected to be positive. □

To test this prediction, I compute expected usage of containerization over a time horizon of 20 years using previously estimated containerized trade.[46,47] This variable's coefficient measures the impact of expectations about future usage of containerized shipping on the decision to adopt containerization.

[45] The maritime distance between two countries is the shortest distance between all their ports. Maritime distances between ports come from "Reeds Maritime Distance Tables" (Reynolds and Caney (2010)), which is the standard reference in the shipping business. See Appendix A for more detail.

[46] This time horizon is long enough to capture the time period that policymakers use in their adoption decisions and short enough that it can be calculated for the majority of the countries. Using time horizons of 10 and 50 years does not qualitatively change my results.

[47] I set the discount rate to zero, but using higher values of the discount rate does not qualitatively change the results.

Prediction 6. *Higher adoption costs decrease the likelihood of adoption of containerization.*

Proof. Given the adoption condition (11), the coefficient of log adoption costs Γ_j in equation (14) is expected to be negative. □

Prediction 7. *Higher net port revenues increase the likelihood of adoption of containerization.*

Proof. Given the adoption condition (11), the coefficient of log net port revenues $(\tilde{\phi}_j - \omega_j)$ in equation (14) is expected to be positive. □

For testing predictions 6 and 7, I use observable economic and intuitional variables such as real per capita GDP, indexes of ethnic and linguistic fractionalization, and an index of constraints on the chief executive. Real per capita GDP is a proxy for both adoption costs and net port revenues. The reasons are as follows: First, the quality of institutions and government are important determinants of the economic and political cost of building any new infrastructure, in particular a container port, and La Porta et al. (1998) find that richer countries can better afford good institutions and good governments than poor countries. Second, La Porta et al. (2008) show that higher income per capita is generally associated with better shareholder and creditor protection and more developed financial markets, which are important determinants of the cost of financing a new container port. Finally, income per capita is also associated with port efficiency, which affects port revenues. In a study of the determinants of shipping costs in the U.S., Clark et al. (2004) show that using per capita GDP as an indirect measure of port efficiency delivers results that are similar to those obtained using their "more noisy measure of port efficiency" (p. 435). The other two institutional measures proxy for adoption costs. According to La Porta et al. (1998), political divergence in society—between ethnic and linguistic interests—has an adverse effect on government quality and performance. In addition, the political economy literature has identified constraints on the chief executive as important impediments to decisionmaking and barriers to infrastructure development. All told, for predictions 6 and 7 to hold, I expect real per capita GDP to have a positive impact on adoption and the institutional indexes (ethnic and linguistic fractionalization and constraints on the chief executive) to have a negative impact on adoption.

Appendix A provides additional detail on the construction of the explanatory variables described above, as well as data sources. Table I reports descriptive statistics.

IV Econometric Evidence

In this section, I test the country-level predictions from the theory. I start with the empirical strategy, followed by a discussion of estimation results.

Empirical strategy: To test Predictions 1 through 4, I estimate the share of containerized trade as follows:

$$\begin{aligned}\ln(ST^c_{j,t}) = \gamma_0 &+ \gamma_1 rail_{j,t} + \gamma_2 roads_{j,t} + \gamma_3 \ln(GDP)_{j,t} + \gamma_4 NDist_{j,t} \\ &+ \gamma_5 Nsize_{j,t} + \gamma_6 Nrail_{j,t} + \gamma_7 Nroads_{j,t} + \gamma_8 NGDP_{j,t} \\ &+ \gamma_9 \mathbf{Y}_{j,t} + \gamma_j + \gamma_a + \varepsilon_{j,t} \ , \end{aligned} \qquad (21)$$

where subscript j indicates country and subscript t indicates year.[48] The dependent variable, $\ln(ST^c_{j,t})$, is the natural logarithm of containerized trade divided by general cargo trade.[49] *rail* is the length of railway lines, *roads* is the length of paved roads, and $\ln(GDP)$ is log real GDP. The prefix N indicates trade-weighted averages over the container network: $NDist$ is average distance, $Nsize$ is average number of adopters, $Nrail$ is average length of railway lines, $Nroads$ is average length of paved roads, and $NGDP$ is average log real GDP. Vector $\mathbf{Y}$ includes a set of control variables such as the number of years since adoption, log population, the share in world trade, a dummy for oil exporters, a dummy for banking crises, and a dummy for the period when the Suez Canal was closed).[50] Country and year-of-adoption fixed effects are denoted by γ_j and γ_a. These dummies control for time-invariant country-specific characteristics and factors that are common to all countries that have adopted containerization in the same year, respectively. Finally, $\varepsilon_{j,t}$ is an error term that captures any remaining unobserved determinants of usage of containerization.

The estimating equation for the adoption decision, which I use to test Predictions 5

[48]While it would be very interesting to conduct a similar analysis on individual ports, such an analysis requires additional data collection. Importantly, to construct trade-weighted network measures, I would need data on port-to-port trade for all ports over the period 1956–2008. This analysis is therefore outside the scope of this paper.

[49]Country-level containerized and general cargo trade are constructed by aggregating trade volumes for all ports in each country.

[50]The closure of the Suez Canal between 1967 and 1975 led to longer and more expensive journeys between Asia and Europe as ships had to make the long voyage around the Cape of Good Hope.

through 7, is

$$\ln\left(\frac{\lambda\left(t|.\right)}{1-\lambda\left(t|.\right)}\right)=\alpha_t \quad + \quad \beta_1\ln(\tilde{T^c_{j,t}})+\beta_2\ln(GDP)_{j,t}+\beta_3 frac^1_j+\beta_4 frac^2_j$$
$$+ \quad \beta_5 exec+\beta_6\mathbf{Z}_{j,t}+\vartheta_{j,t}\ . \qquad (22)$$

I construct the dependent variable—the log odds ratio of adoption of containerization—in two steps. First, I set the adoption indicator variable equal to one in the years when a country has at least one container port and zero otherwise. Second, for each country, I drop all observations corresponding to the years after adoption; that is, once a country adopts containerization, it is dropped from the estimation in the following years. Based on key events that have influenced the diffusion of containerization (see Section I), α_t includes dummies for the following time periods: 1956–1965, 1966–1974, 1975–1983, and 1984–2008. The other explanatory variables are log expected containerized trade over a time horizon of 20 years ($\ln(\tilde{T^c_{j,t}})$), log real per capita GDP ($\ln(GDP)$), ethnic fractionalization ($frac^1$), linguistic fractionalization ($frac^2$), and constraints on the chief executive ($exec$). Finally, vector $\mathbf{Z}$ includes a set of control variables (log area, log length of coastline, log trade openness, and oil export share), and $\vartheta_{j,t}$ is an error term that captures any remaining unobserved determinants of adoption of containerization.

Results: Table II presents ordinary-least-squares (OLS) estimates of equation (21). Since the estimation is conditional upon the decision to adopt, I use only observations with positive values of containerized trade. Standard errors are clustered by country to correct for residual dependence between observations of the same country in different years.

Columns 1, 2, and 6 of Table II present coefficient estimates for the full sample. In columns 3 and 4 the sample is split into low to medium-low income countries and high to medium-high income countries.[51] Columns 5 refers to the full sample excluding oil exporting countries (countries with oil export shares higher than 80 percent).

Table II reveals four robust features of the data which are consistent with the predictions of the model. First, in line with the first part of Prediction 1, reductions in fixed costs increase usage of containerization, particularly through improvements in rail intermodal potential. A one-standard-deviation increase in the length of railway lines (about 29 thousand miles) increases the share of containerized shipping by near 60 percent (using the coefficient estimates in Column 2). This corresponds to almost 30 percentage-point increase in the share of containerized shipping of the average observation in the sample.

[51] See Appendix A for details on income classification.

Furthermore, the impact of the railways is substantially larger in low to medium-low income countries than in high to medium-high income countries, although the coefficient estimate in the subsample of low to medium-low income countries is statistically insignificant. In contrast, the coefficient estimates for average railway and paved-road length in the container network provide little support for the second part of Prediction 1; other adopters' fixed costs have a small impact on usage of containerization.[52]

Second, the size of the container network has a large and positive impact on usage of containerization (Prediction 2). A one-standard-deviation increase in the share of containerized trade partners raises the fraction of containerized trade by over 210 percent. Moreover, this impact is three times as large in low to medium-low income countries than in high to medium-high income countries. Furthermore, the small and statistically insignificant coefficient estimate for network size in Column 6 indicates that it is the number of trade partners, and not the overall number of container ports, that affects usage of the technology.

The third finding in Table II is related to Prediction 3. In the full sample, domestic income has a small and positive impact on usage of containerization, but in low to medium-low income countries, additional income has a larger effect on usage of containerization (see Column 4). In the latter countries, a one-percent increase in domestic income raises the share of containerized shipping by the same one percent. Trading with rich partners also affects usage of containerization, but its influence is small. For the full sample, a 10-percent increase in average network income raises containerized shipping only half a percent. As the estimates in columns 3 and 4 indicate, however, this effect is only a little stronger in low to medium-low income countries than in high to medium-high income countries.

Finally, the coefficient estimates for the average distance to the trade network are mixed and indicate little impact of distance on the share of containerized shipping. Despite containerization's cost-saving advantages, in particular because of economies of scale, increasing the average distance cargo is shipped does not seem to affect usage of containerization, after controlling for other factors.

Table C.1 in the appendix presents robustness checks to address simultaneity-bias concerns about the impact of network size on usage of containerization.[53] First, I consider a larger lag for network size: five years instead of one. This should mitigate the

[52]Entering the two variables separately does not change the results.

[53]If two countries affect each other simultaneously, it is hard to identify empirically the actual impact that a country's network of adopters has on its usage of containerization. This simultaneity bias is what Manski (1993) called "the reflection problem."

simultaneity problem since a country's decision to increase usage of containerization (an aggregate of its firms' individual decisions) should have no influence on its trade partners' adoption decisions five years back. However, the identification problem may still be present if countries affect each other through expectations about future actions. To address this possibility, I run two additional tests. First, I exclude countries with large shares in world trade (higher than 10 percent). While it is possible that expectations about future usage of containerization by countries with large world-trade shares may affect the adoption decision of several countries in their trade network (reverse causality), it seems less plausible that expectations about future usage of containerization by countries with small trade shares would matter for other countries' adoptions. Second, I exclude countries that adopted containerization before 1970. This controls for the possibility that expectations about usage of containerization by early adopters affect other countries' adoption decisions. All told, the results in Table C.1 show that the coefficient estimates presented in Table II survive these three robustness checks.

I also investigate the role of neighbors' adoption on usage of containerization. I define neighbors in three different ways: (1) countries with a common border, (2) countries that either have a common border or are within 500 miles of each other, and (3) countries that were in a colonial relationship at some point after 1945. Tables C.2, C.3, and C.4 in the appendix present results from three sets of regressions which are similar to Column 2 of Table II, except that the container network is divided into neighbors and non-neighbors. All three sets of coefficient estimates show no distinctive effect of neighboring countries' adoption on usage of containerization. Adoption by other countries matters for usage of containerization because of trade linkages and not because of geographical proximity or past colonial relationships.

Table III presents results from estimating the logistic discrete-time hazard in equation (22). Expected containerized trade is computed over a period of 20 years using both the estimated share of containerized trade (derived from specification 2 of Table II) and realized general cargo trade.[54] Since containerized trade is measured with sampling error, I estimate standard errors by bootstrapping the results 1000 times.[55] Column 1 is my baseline regression to test Predictions 5 through 7. The coefficient estimate for expected

[54]Figure C.2 in the appendix compares observed and estimated shares of containerized trade and shows that observed shares of containerized trade fall well within the 95-percent confidence interval of their estimated values.

[55]The observations are resampled with replacement, and the number of replications is large enough that the results do not vary substantially across computations.

containerized trade confirms Prediction 5 and suggests a strong impact of expectations of future usage of containerization on the likelihood of adoption. A one-standard-deviation increase in expected containerized trade over a 20-year period (2 percent) makes a country almost three times more likely to adopt containerization (exp(2*0.501)).[56] Real income per capita also raises the likelihood of adoption. Increasing real per-capita income by one percent makes a country over three times more likely to adopt. To the extent that real income is a good proxy for both adoption costs and port efficiency, this evidence confirms Predictions 6 and 7. Moreover, the impact of adoption costs is confirmed further by the negative coefficient of the index of ethnic fractionalization, although not statistically significant. The impact of linguistic fractionalization, however, goes in the opposite direction. This coefficient estimate, though not statistically significant, indicates that linguistically more diverse countries are more likely to adopt containerization. This result may be explained by the finding in Alesina et al. (2003) that while ethnic fractionalization is highly negatively correlated with institutional variables such as schooling and telephones per capita, linguistic fractionalization is less correlated with these variables. The coefficient estimates for the index of constraints on the chief executive are inconclusive; they show different signs across estimations and are not statistically significant.

Columns 2 and 3 include lagged trade shares with the first five adopters (the United States, Australia, Belgium, Netherlands, and the United Kingdom). These additional regressors test potential economy of scale effects and the role of trade with early adopters as a vehicle of transmission of new technology. Column 2 shows results for the full sample and Column 3 excludes oil exporters. Previous coefficient estimates (Column 1) are robust to adding these additional regressors. In addition, these new estimates show that countries with larger shares of trade with the United States—the first and largest user of containerization—are more likely to adopt containerization. Excluding oil exporters (Column 3), a 10-percentage-point increase in the share of trade with the United States makes a country almost twice as likely to adopt.[57] While the coefficient estimates in Column 3 for trade with the Netherlands and the U.K. are also positive and of similar magnitude, they are not statistically significant once trade with the United States is included.

[56] Tables C.5 and C.6 in the appendix show qualitatively similar coefficient estimates using 10- and 50-year horizons.

[57] These results are robust to excluding Canada and Mexico from the estimation, two countries which trade mainly with the United States, but mostly by land.

V Conclusion

Containerization is one of the most important innovations affecting international trade in the second half of the twentieth century. First used in 1956, it quickly became the central piece of today's global economy. This paper examines containerization's international diffusion from two complementary perspectives, the extensive and the intensive margins. It has made three contributions to our understanding of the diffusion of technologies with network effects. First, using a new dataset that I collected, this paper shows that adoption of container-port infrastructure, which follows an S-shaped pattern, was exceptionally rapid and usage of containerized shipping increased much more slowly. My second contribution is to estimate the determinants of usage of containerization, using country-level predictions from a theoretical model that is consistent with the data. I find that usage of containerization increases with firms' fixed costs and the size and average income of the container network. The impact of fixed costs is derived through a measure of intermodal potential that uses the length of the domestic network of railway lines. Finally, my third contribution is to shed light on the determinants of adoption. I find that the timing of adoption depends on expected future usage of containerization, adoption costs, and trade with the United States, the first and largest user of containerized shipping.

These findings emphasize the importance of the inland transportation network as a barrier to trade. While the bulk of the international trade literature has focused on international barriers to trade, especially barriers related to geographical frictions and national borders, internal trade barriers have received less attention. My conclusions show that government policies that enhance inland intermodality can have a significant impact on the diffusion of technologies that alter the way international trade works and how the global economy is linked together. In addition, my results also point to the relevance of trade linkages for the diffusion of technology. Trade relationships with early adopters, rich countries, and countries that are in the center of the international trade network are key in the adoption of new technologies.

References

Alesina, Alberto, Arnaud Devleeschauwer, William Easterly, Sergio Kurlat, and Romain Wacziarg, "Fractionalization," 2003, *8* (2), 155–194.

Baier, Scott L. and Jeffrey H. Bergstrand, "The growth of world trade: tariffs, transport costs, and income similarity," *Journal of International Economics*, February 2001, *53* (1), 1–27.

Battisti, Giuliana and Paul Stoneman, "Inter- and Intra-firm Effects in the Diffusion of New Process Technology," *Research Policy*, 2003, *32* (9), 1641 – 1655.

— and — , "The intra-firm diffusion of new process technologies," *International Journal of Industrial Organization*, February 2005, *23* (1-2), 1–22.

Bogart, Dan, "Neighbors, networks, and the development of transport systems: Explaining the diffusion of turnpike trusts in eighteenth-century England," *Journal of Urban Economics*, 2007, *61* (2), 238 – 262.

Broeze, Frank, *The Globalisation of the Oceans: Containerisation From the 1950s to the Present*, Vol. 23 of *Research in Maritime History*, St. John's, Newfoundland: International Maritime Economic History Association, 2002.

Cabral, Luis M. B., "On the adoption of innovations with 'network' externalities," *Mathematical Social Sciences*, June 1990, *19* (3), 299–308.

Canning, David, "A Database of World Stocks of Infrastructure: 1950-1995," *The World Bank Economic Review*, 1998, *12* (3), 529–548.

Central Intelligence Agency, "The World Factbook," 1990.

— , "The World Factbook," 2011.

Clark, Ximena, David Dollar, and Alejandro Micco, "Port Efficiency, Maritime Transport Costs, and Bilateral Trade," *Journal of Development Economics*, 2004, *75* (2), 417 – 450.

Comin, D. and B. Hobijn, "Cross-country Technology Adoption: Making the Theories Face the Facts," *Journal of Monetary Economics*, 2004, *51* (1), 39–83.

Comin, Diego and Bart Hobijn, "An Exploration of Technology Diffusion," *American Economic Review*, 2010, *100* (5), 2031–59.

— , — , and Emilie Rovito, "A new approach to measuring technology with an application to the shape of the diffusion curves," *The Journal of Technology Transfer*, January 2008, *33* (2), 187–207.

David, Paul A. and Trond E. Olsen, "Technology Adoption, Learning Spillovers, and the Optimal Duration of Patent-based Monopolies," *International Journal of Industrial Organization*, 1992, *10* (4), 517–543.

Drucker, Peter F., *Innovation and Entrepreneurship*, Butterworth-Heinemann, 2007.

Eichengreen, Barry and Douglas A. Irwin, "Trade blocs, currency blocs and the reorientation of world trade in the 1930s," *Journal of International Economics*, February 1995, *38* (1-2), 1–24.

Estevadeordal, Antoni and Raymond Robertson, "Do Preferential Trade Agreements Matter for Trade? FTAA and the Pattern of Trade," in A. Estevadeordal, D. Rodrik, A.M. Taylor, and A. Velasco, eds., *Integrating the Americas: FTAA and Beyond*, Cambridge: Harvard University Press, 2004.

_ , Brian Frantz, and Alan M. Taylor, "The Rise and Fall of World Trade, 1870-1939," *The Quarterly Journal of Economics*, 2003, *118* (2), 359–407.

Farrell, Joseph and Garth Saloner, "Standardization, Compatibility, and Innovation," *RAND Journal of Economics*, Spring 1985, *16* (1), 70–83.

_ and _ , "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation," *The American Economic Review*, 12 1986, *76* (5), 940–955.

Frankel, Jeffrey A. and Shang-Jin Wei, "Emerging Currency Blocs," Working Paper 4335, National Bureau of Economic Research April 1993.

Geroski, P.A., "Models of Technology Diffusion," *Research Policy*, 2000, *29* (4-5), 603–625.

Glick, Reuven and Andrew K. Rose, "Does a currency union affect trade? The time-series evidence," *European Economic Review*, June 2002, *46* (6), 1125–1151.

Goolsbee, Austan and Peter J Klenow, "Evidence on Learning and Network Externalities in the Diffusion of Home Computers," *Journal of Law and Economics*, October 2002, *45* (2), 317–43.

Gort, M. and S. Klepper, "Time paths in the diffusion of product innovations," *The Economic Journal*, 1982, *92* (367), 630–653.

Gowrisankaran, Gautam and Joanna Stavins, "Network Externalities and Technology Adoption: Lessons from Electronic Payments," *RAND Journal of Economics*, Summer 2004, *35* (2), 260–276.

Griliches, Zvi, "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrica*, 1957, *25* (4), 501–522.

Helpman, Elhanan, Marc J. Melitz, and Stephen R. Yeaple, "Export versus FDI with Heterogeneous Firms," *The American Economic Review*, 2004, *94* (1), 300–316.

Heston, Alan, Robert Summers, and Bettina Aten, *Penn World Table Version 7.0*, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, June 2011.

Hummels, David, "Transportation Costs and International Trade in the Second Era of Globalization," *The Journal of Economic Perspectives*, 2007, *21* (3), 131–154.

IMF, *Direction of Trade Statistics: 1948-1980*, Washington D.C.: Washington D.C.: IMF, 2002.

_ , "Trade and Financial Integration," in "World Economic Outlook," Washington D.C.: IMF, September 2002, chapter III, pp. 108–146.

_ , *Direction of Trade Statistics*, Washington D.C.: Washington D.C.: IMF, May 2013.

Institute of Shipping Economics and Logistics, *Shipping Statistics Yearbook*, Bremen, Germany: Institute of Shipping Economics and Logistics, 1968, 1975, 1977, 1979, 1981, 1984, 1986–2009.

_ , *Shipping Statistics Yearbook*, Bremen, Germany: Institute of Shipping Economics and Logistics, 2008.

Katz, Michael L. and Carl Shapiro, "Network Externalities, Competition, and Compatibility," *American Economic Review*, 1985, *75* (3), 424–40.

Katz, Michael L and Carl Shapiro, "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy*, August 1986, *94* (4), 822–41.

Kele, Vivek, "The Rise and Rise of LCL," *Logistics Week*, February 2011, *LOG.India.*

Kendall, L.C., *The Business of Shipping*, fifth ed., Cornell Maritime Press, 1986.

La Porta, Rafael, Florencio Lopez de Silanes, and Andrei Shleifer, "The Economic Consequences of Legal Origins," *Journal of Economic Literature*, 2008, *46* (2), pp. 285–332.

_ , Florencio Lopez de Silanes, Andrei Shleifer, and Robert Vishny, "The Quality of Goverment," NBER Working Papers 6727, National Bureau of Economic Research, Inc September 1998.

Laeven, Luc and Fabian Valencia, "Resolution of Banking Crises: The Good, the Bad, and the Ugly," IMF Working Papers 10/146, International Monetary Fund, Washington D.C. 2010.

Levinson, Marc, *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*, Princeton University Press, 2008.

Lloyd's of London Press, *Lloyd's Ports of the World*, Colchester, Essex, UK: Lloyd's of London Press, 1982–1996.

Mandryk, Wally, "Measuring Global Seaborne Trade," May 2009.

Mansfield, E., "Technical change and the rate of imitation," *Econometrica: Journal of the Econometric Society*, 1961, pp. 741–766.

Manski, Charles F., "Identification of Endogenous Social Effects: The Reflection Problem," *The Review of Economic Studies*, 1993, *60* (3), 531–542.

Melitz, Marc J., "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 2003, *71* (6), 1695–1725.

Mohammed, Saif I. Shah and Jeffrey G. Williamson, "Freight rates and productivity gains in British tramp shipping 1869-1950," *Explorations in Economic History, Elsevier*, April 2004, *41* (2), 172–203.

Morison, Robert F., "Containerization: Good and Bad News," *The Journal of Commerce and Commercial*, 1977, pp. 1A, 15A.

National Magazine Co., *Containerisation International Yearbook*, London : National Magazine Co., 1968, 1970–2008.

_ , "Containerisation International Magazine," September 1983.

_ , "Containerisation International Magazine, Market Analysis," 2009.

North, Douglass, "Ocean Freight Rates and Economic Development 1750-1913," *The Journal of Economic History*, 1958, *18* (4), 537–555.

_ , "Sources of Productivity Change in Ocean Shipping, 1600-1850," *Journal of Political Economy*, 09 1968, *76* (5), 953–970.

O'Hara, Clifford B., "International Container Movements: Problems and Oportunities 1974-1980," in American Society of Traffic and Transportation, ed., *Transport and Logistics Challenges, 1974-1980*, 28th annual meeting, Kansas City, Missouri 1974, pp. 129–141.

O'Rourke, K.H. and J.G. Williamson, *Globalization and History: The Evolution of a Nineteenth-century Atlantic Economy*, MIT Press, 2001.

Pacific Maritime Association, “Annual Report,” 1996.

Reynolds, J.E. and R.W. Caney, *Reeds Marine Distance Tables: 59,000 Distances and 500 Ports Around the World* Reeds Professional Series, 11th ed., Adlard Coles Nautical, 2010.

Rodrigue, Jean-Paul, Claude Comtois, and Brian Slack, *The Geography of Transport Systems*, Routledge Chapman & Hall, 2013.

Saloner, Garth and Andrea Shepard, “Adoption of Technologies with Network Effects: An Empirical Examination of the Adoption of Automated Teller Machines,” *The RAND Journal of Economics*, 1995, *26* (3), 479–501.

Shipping World, *Ports of the World*, London, UK: Shipping World, 1946–1981.

Singer, J.D. and J.B. Willett, *Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence: Modeling Change and Event Occurrence*, Oxford University Press, 2003.

Skinner, J. and D. Staiger, “Technology adoption from hybrid corn to beta blockers,” Technical Report, National Bureau of Economic Research 2005.

Stoneman, Paul and Giuliana Battisti, “The Diffusion of New Technology,” in Bronwyn H. Hall and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation*, Vol. 2, North Holland, 2010, chapter 17.

UNCTAD, *Review of Maritime Transport*, United Nations Publications, 2013.

U.S. Department of Transportation, “Glossary of Shipping Terms,” May 2008.
World Development Indicators

World Development Indicators*, Washington D.C.: The World Bank, 2011.*

VI Tables and Figures

TABLE I. **Descriptive statistics**

	Obs.	Mean	St. Dev.	Min.	Max.	Median
Share containerized trade	2293	0.51	0.27	0	1	0.51
Log containerized trade	2829	14.8	1.95	7.63	19.7	14.6
Log general cargo trade	2376	16.0	1.56	11.6	20.1	15.9
Length railway lines (1M Km)	4487	0.009	0.029	0	0.33	0.002
Length paved roads (1M Km)	4071	0.10	0.38	0.000006	3.82	0.01
Log real GDP	5403	24.5	2.11	18.2	30.3	24.5
Log real GDP p.c.	5403	8.43	1.29	4.77	11.9	8.48
Distance to trade network	5997	8.18	0.44	6.82	9.11	8.17
Network log real GDP	5963	22.2	8.21	0.001	29.7	26.2
Network length railways	5646	0.056	0.042	0.004	0.25	0.04
Network length paved roads	5645	0.68	0.51	0.000008	3.09	0.56
Container network size	6406	0.77	0.36	0	1	0.98
Network container ports	5963	12.8	7.97	0.0004	44.9	13.0
Executive contraints	5339	4.08	2.37	0	7	3
Ethnic fractionalization	6093	0.44	0.27	0.002	0.91	0.44
Linguistic fractionalization	6252	0.36	0.29	0.002	0.90	0.30
Executive contraints	5339	4.08	2.37	0	7	3
Share of trade with USA	6149	0.16	0.17	0	1	0.1
Share of trade with AUS	6149	0.016	0.056	0	0.93	0.004
Share of trade with BEL	6149	0.026	0.043	0	0.52	0.016
Share of trade with NLD	6149	0.035	0.032	0	0.42	0.026
Share of trade with GBR	6149	0.081	0.10	0	1	0.047

TABLE II. **Usage of containerization**

	(1)	(2)	(3)	(4)	(5)	(6)
Length railway lines (1M Km)	11.41**	15.35**	9.49*	69.80	15.66**	13.81**
	(2.25)	(3.09)	(3.64)	(71.21)	(3.09)	(2.47)
Length paved roads (1M Km)	0.18	-0.04	-0.83	-0.01	-0.03	0.02
	(0.25)	(0.31)	(0.51)	(0.18)	(0.31)	(0.25)
Log real GDP	0.43	0.24	-0.22	0.95**	0.23	0.25
	(0.27)	(0.24)	(0.31)	(0.29)	(0.26)	(0.25)
Container network size		3.17**	3.27*	10.64**	3.13**	
		(0.91)	(1.35)	(2.50)	(0.91)	
Network container ports						0.03
						(0.02)
Distance to trade network	0.08	-0.19	-0.31	-1.07	-0.03	0.08
	(0.54)	(0.45)	(0.90)	(0.81)	(0.54)	(0.48)
Network log real GDP		0.04*	0.03	0.05+	0.04*	0.08**
		(0.02)	(0.04)	(0.03)	(0.02)	(0.02)
Network length railways		8.54	9.67	-0.76	9.44	7.92
		(6.82)	(10.82)	(5.87)	(7.02)	(6.77)
Network length paved roads		-0.32	0.25	-0.66	-0.48	-0.69
		(0.35)	(0.60)	(0.45)	(0.34)	(0.47)
Observations	1643	1643	903	740	1565	1643
R^2	0.65	0.69	0.72	0.72	0.69	0.67
Nr. countries	74	74	36	38	70	74
Country f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Year adoption f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Sub-sample			H/MH income	L/ML income	Excl. oil exporters	

Note: The dependent variable is the share of containerized shipping, in logs. All explanatory variables are lagged one year, except the instrument. Controls (not shown): constant, number of years since adoption, log population, share in world trade, dummy for oil exporter, dummy for banking crisis, and dummy for the period when the Suez Canal was closed. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

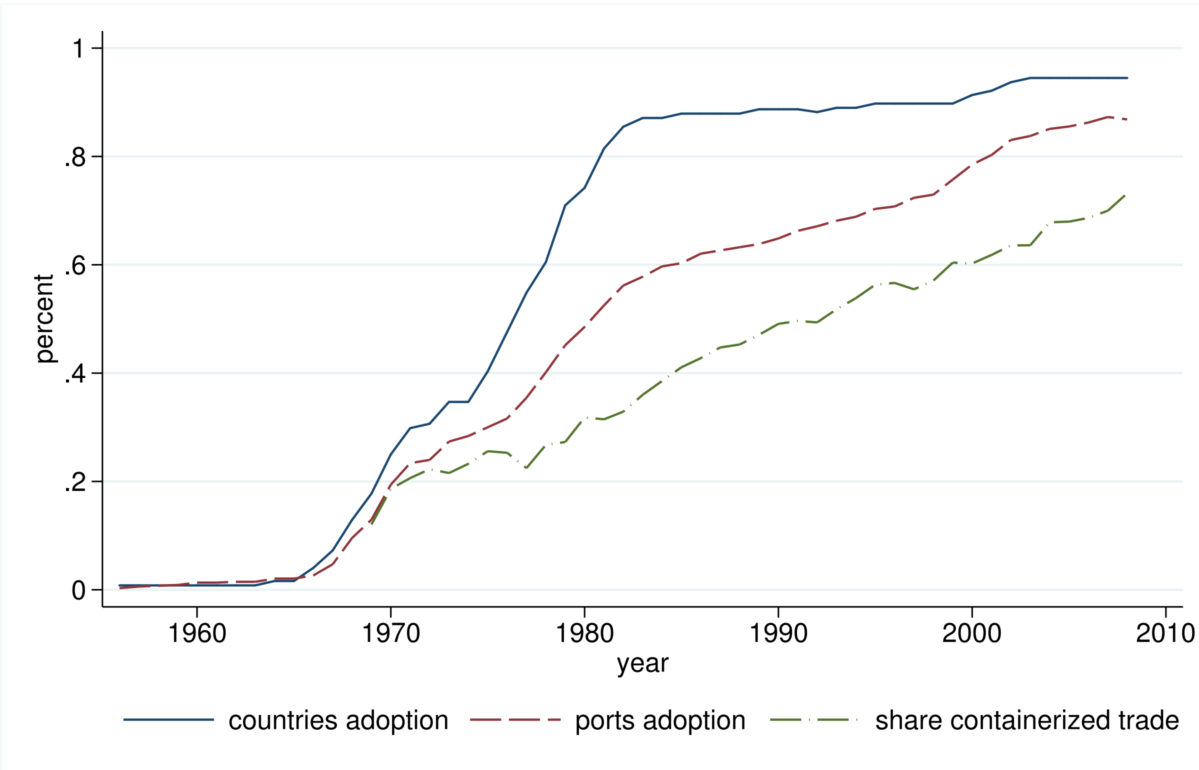
TABLE III. **Adoption of containerization**

	(1)	(2)	(3)
Predicted log cont. trade 20yr	0.501*	0.480	0.652+
	(0.234)	(0.327)	(0.340)
Log real GDP p.c.	1.174**	0.972+	1.261*
	(0.436)	(0.538)	(0.595)
Ethnic fractionalization	-0.523	-0.605	-0.846
	(1.872)	(2.932)	(2.718)
Linguistic fractionalization	1.983	1.987	2.336
	(1.522)	(2.400)	(2.223)
Executive contraints	0.042	-0.022	0.117
	(0.101)	(0.134)	(0.163)
Share of trade with USA		1.256	5.997+
		(2.945)	(3.351)
Share of trade with AUS		1.111	-3.921
		(18.644)	(17.557)
Share of trade with BEL		4.344	-1.569
		(24.202)	(29.861)
Share of trade with NLD		-2.625	6.791
		(11.267)	(12.341)
Share of trade with GBR		3.624	5.607
		(4.402)	(4.658)
Dummy 1956-1965	-5.265		
	(5.187)		
Dummy 1966-1974	-2.090	-2.364	-3.317
	(5.149)	(5.316)	(5.364)
Dummy 1975-1983	-0.268	-0.462	-0.976
	(5.160)	(5.261)	(5.310)
Observations	407	329	312
Log-likelihood	-105.689	-100.899	-90.897
Sub-sample			Excl. oil exporters

Note: The dependent variable is an indicator variable that takes the value one at the year of adoption and zero otherwise. For each country, I drop all observations corresponding to the years after adoption; that is, once a country adopts containerization, it is dropped from the estimation in the following years. Controls (not shown): log area, log length of coastline, log trade openness, and oil export share. Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

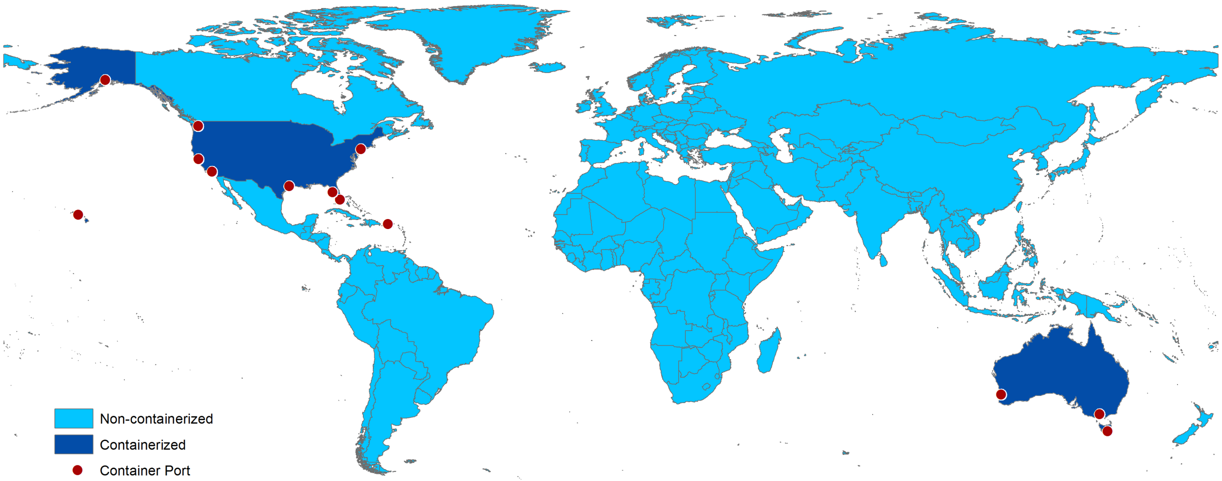
Figure I

Diffusion of containerization in the period 1956–2008: adoption and usage

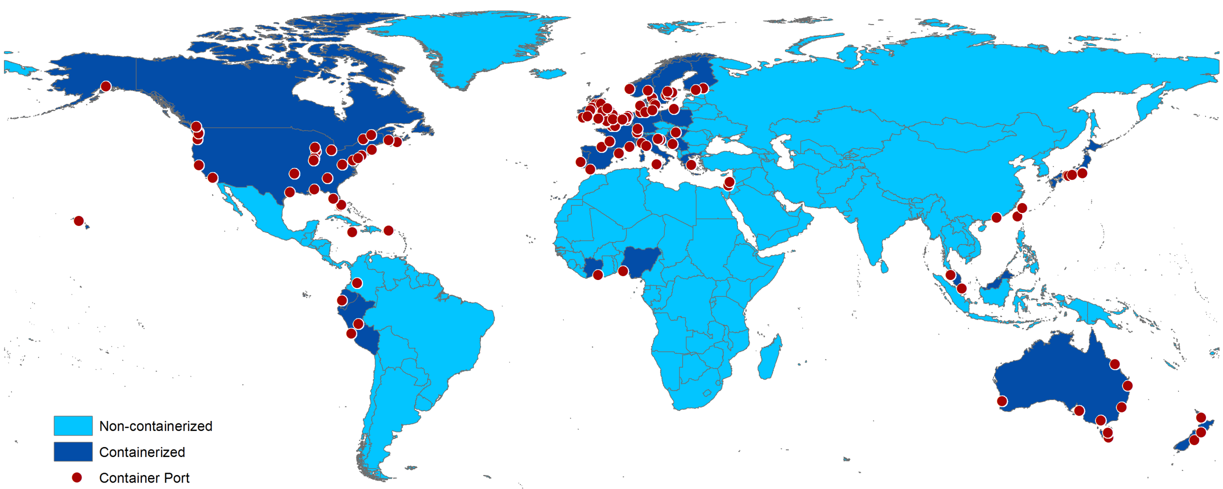


Source: Author's dataset.

Figure II. **Geographical diffusion of containerization: 1965 and 1970**



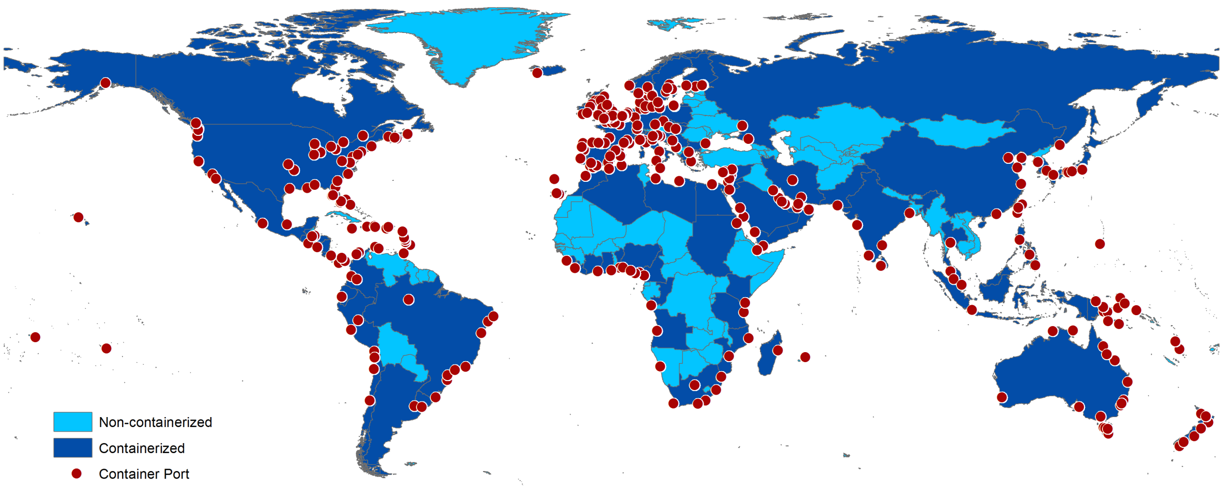
(a) 1965



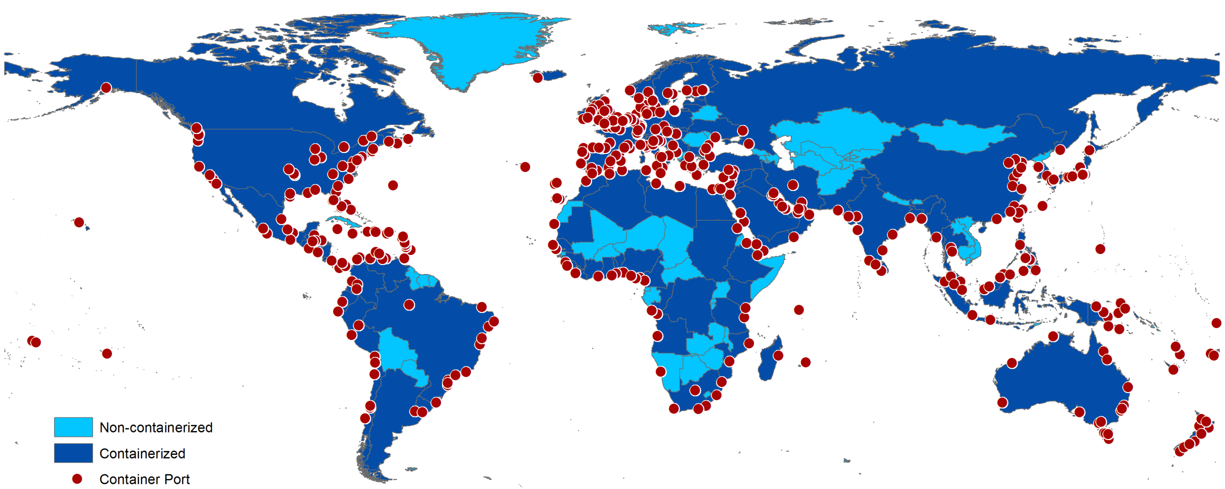
(b) 1970

Source: Author's dataset.

FIGURE III. **Geographical diffusion of containerization: 1980 and 1990**



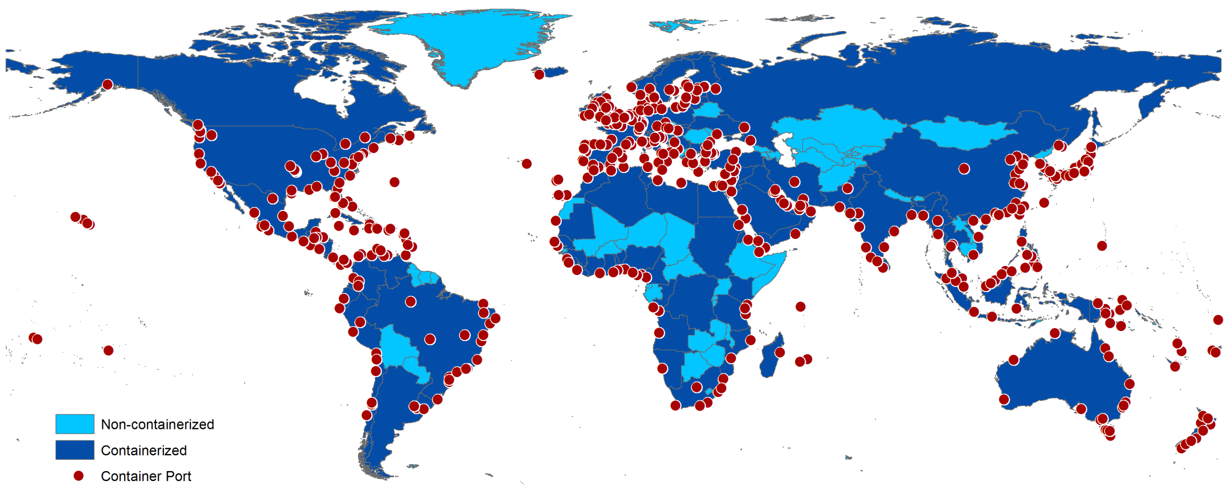
(a) 1980



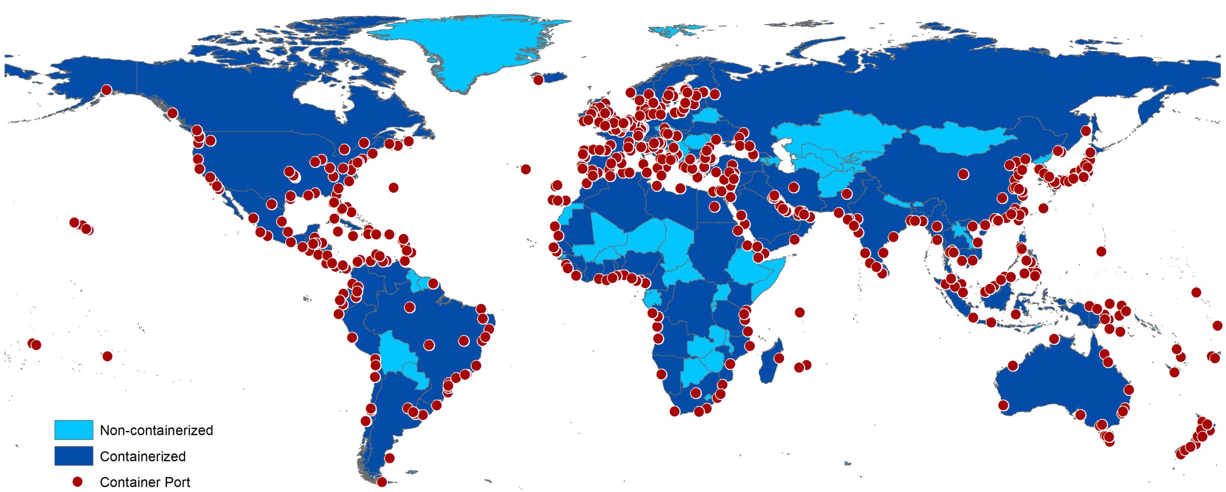
(b) 1990

Source: Author's dataset.

FIGURE IV. **Geographical diffusion of containerization: 2000 and 2008**



(a) 2000



(b) 2008

Source: Author's dataset.

Figure V. **Exporters' choice of shipping technology**

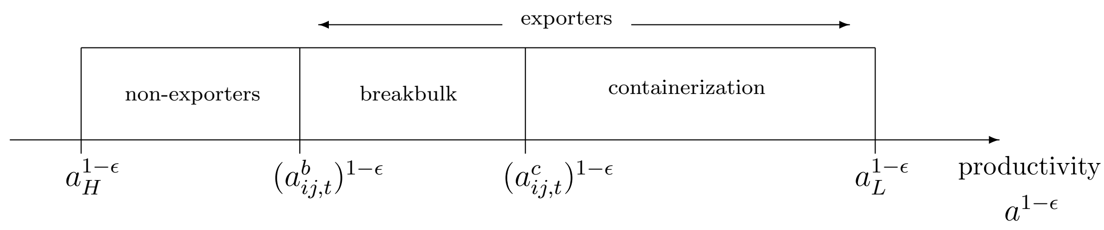
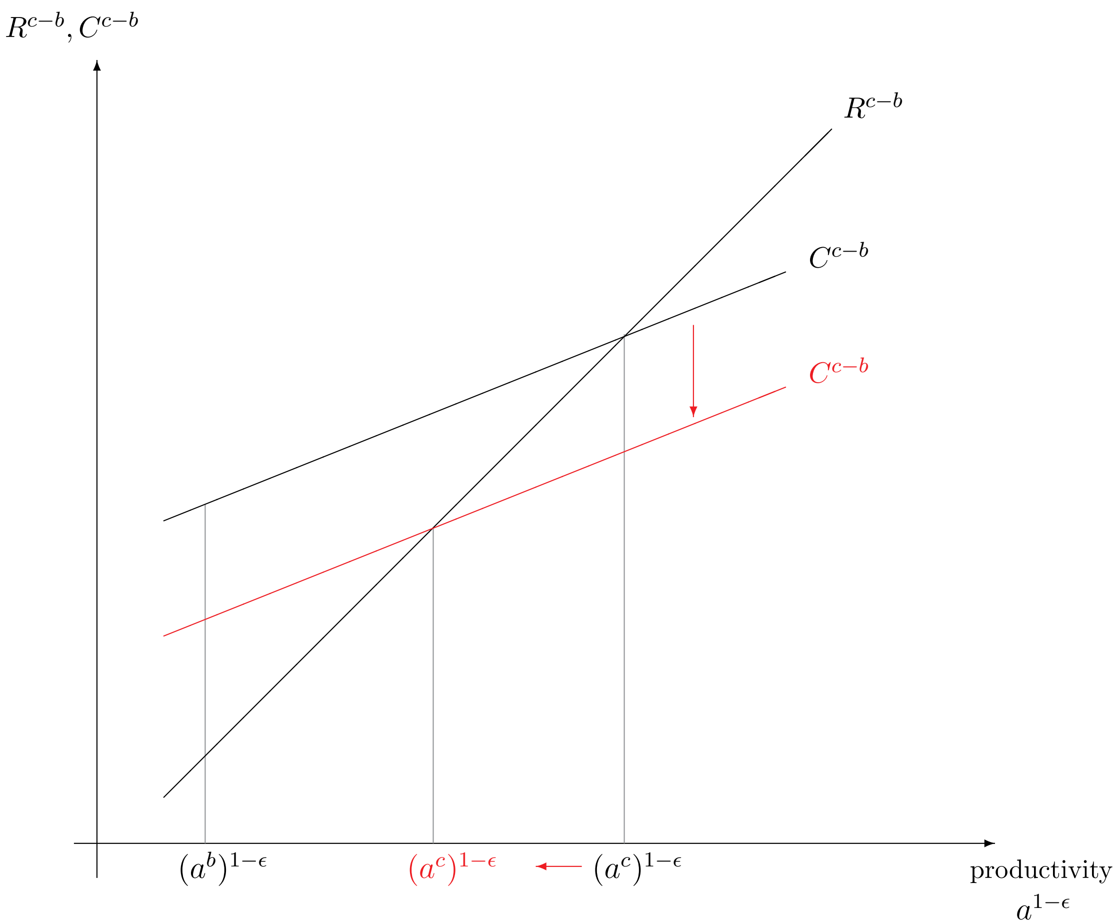


Figure VI. **Exporters' choice of shipping technology**



A Data Appendix

A1 Containerization Dataset

Data sources: I used the three following publications to build my dataset with port-level information on the initial adoption decision and the share of trade that is containerized. All three are annual publications of the container and shipping industries, available only in book format for most of the period from 1956 to the present.

- *Containerisation International* yearbooks for 1968 and 1970–2010: among other information, each book reports container handling statistics for all container ports.
- *Lloyd's Ports of the World* for 1946–1996: among other information, each book describes cargo handling facilities for all ports in the world. and
- *Shipping Statistics* yearbooks for 1968, 1975, 1977, 1979, 1981, 1984, 1986–2009: each book contains a section called "Port Surveys," with detailed port statistics for a large number of ports worldwide and for several years prior to the publication year. These statistics include cargo traffic volume, split by origin/destination (foreign and domestic) and by nature (general cargo, dry and liquid bulk, and oil products).

Coding rules: To determine a port's year of adoption of containerization, I read the verbal descriptions of ports' facilities in the *Containerisation International* yearbooks. The year of adoption is the year of the first mention of container facilities being in operation at the port. If there is no verbal description, I substitute the year for which the earliest container statistics are available. Since earlier yearbooks lack detailed information for many ports, I also use port descriptions from the *Lloyd's Ports of the World* books to double-check the date when a port was first able to handle containers. A country's adoption year is the year when its first port adopted containerization.

To construct a dataset with the share of containerized trade handled at each port, I combined data from the *Containerisation International* yearbooks and the *Shipping Statistics* yearbooks. Not only do these publications complement each other, but they also served as a check on each other. The share of containerized trade is the ratio between the volume of containerized trade and all containerizable trade (in shipping jargon, general cargo trade) regardless of whether it was containerized or shipped in breakbulk. I collected data on general cargo trade volumes from the *Shipping Statistics* yearbooks and data on containerized trade volumes from both the *Containerisation International* yearbooks and the *Shipping Statistics* yearbooks. These data correspond to total loaded and unloaded tonnage, measured in metric tonnes. Where the units of measurement were not metric tonnes (e.g., long tons, short tons, revenue tonnes, or harbour tonnes), I converted the numbers into metric tonnes.

In order to fill in missing values, I also collected data from port websites and requested data directly from port authorities. For ports in Australia, Belgium, Brazil, Brunei, Canada, Chile, Colombia, Germany, Ireland, Mexico, Spain, the United Kingdom, and the United States, I used information available online. For the ports of Oakland and Los Angeles, I used data provided directly by the ports.

Country aggregation: For each country, I sum containerized and general cargo trade across all ports with complete data. This way there is no imbalance when I normalize containerized trade by the scale of containerizable trade, i.e., general cargo trade. I dropped all New Zealand ports, since their units of measurement are not consistent across ports and time. Overall, in a total of 7,367 observations, 520 (which corresponds to 7 percent) were calculated using some imputed data.

Country coverage for year of adoption: Algeria, American Samoa, Angola, Antigua and Barbuda, Argentina, Aruba, Ascension Is., Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Belize, Benin, Bermuda, Brazil, Brunei, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Colombia, Congo (DR), Congo (Republic), Costa Rica, Croatia, Cuba, Cyprus, Czechoslovakia, Czech Republic Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Fiji, Finland, France, French Guiana, French Polynesia, Gabon, Gambia, Georgia, Germany, Ghana, Gibraltar, Greece, Guadeloupe, Guam, Guatemala, Guinea, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Ivory Coast, Jamaica, Japan, Jordan, Kenya, Kiribati, Kuwait, Latvia, Lebanon, Liberia, Libya, Lithuania, Madagascar, Malaysia, Malta, Martinique, Mauritania, Mauritius, Mexico, Montenegro, Morocco, Mozambique, Myanmar, Netherlands, Netherlands Antilles, New Caledonia, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Peru, Philippines, Poland, Portugal, Qatar, Reunion, Romania, Russia, Samoa, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Slovak Republic, Slovenia, Solomon Is., Somalia, South Africa, South Korea, Spain, Sri Lanka, St. Lucia, Sudan, Sweden, Switzerland, Syria, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, United Arab Emirates, United Kingdom, USA, Ukraine, Uruguay, Vanuatu, Venezuela, Vietnam, Yemen, and Yugoslavia.

Country coverage for containerized trade: Albania, Algeria, Angola, Argentina, Ascension Island, Australia, Bahrain, Bangladesh, Belgium, Benin, Brazil, Brunei, Bulgaria, Cabo Verde, Cambodia, Cameroon, Canada, Chile, China, Colombia, Congo (DR), Congo (Rep), Costa Rica, Cuba, Cyprus, Czechoslovakia, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Finland, France, French Guiana, Gabon, Gambia, Georgia, Germany, Ghana, Gibraltar, Greece, Guadeloupe, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, Hong Kong SAR, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Ivory Coast, Jamaica, Japan, Jordan, Kenya, Kiribati, Kuwait, Latvia, Lebanon, Liberia, Libya, Lithuania, Madagascar, Malaysia, Malta, Martinique, Mauritania, Mexico, Montserrat, Morocco, Mozambique, Myanmar, Netherlands, Netherlands Antilles, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Peru, Philippines, Poland, Portugal, Qatar, Reunion, Romania, Sao Tome e Principe, Saudi Arabia, Senegal, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, South Korea, Spain, Sri Lanka, Sudan, Sweden, Syria, Taiwan, Tanzania, Thailand, Togo, Trinidad & Tobago, Tunisia, Turkey, United Arab Emirates, United Kingdom, Uruguay, USA, USSR, Venezuela, Vietnam, Yemen, and Yugoslavia.

Country adoptions: Below are the years when countries adopted containerization, that is, when they build their first container port.

1956	USA
1964	Australia
1966	Belgium, Netherlands, UK
1967	Ireland, New Zealand, Nigeria, Spain
1968	Canada, France, Germany, Italy, Japan, Norway, Sweden, Switzerland*
1969	Denmark, Hungary*, Jamaica, Malaysia, Peru, Singapore, Taiwan
1970	Ecuador, Finland, Germany GDR*, Greece, Hong Kong SAR, Israel, Ivory Coast, Poland, Portugal, Yugoslavia
1971	Brazil, Colombia, India, Philippines, South Africa, USSR
1972	Bahamas*, Bulgaria
1973	Cameroon, Chile, Iceland, Mexico, Trinidad and Tobago
1975	Barbados*, Honduras, Indonesia, Kenya, Mozambique, South Korea, Tanzania, Thailand

1976	Argentina, Aruba*, Benin, Dominican Republic, Guatemala, Haiti, Jordan, Panama, Saudi Arabia, UAE
1977	Bahrain, Cyprus, Iran, Iraq, Kuwait, Lebanon, Morocco, Nicaragua, Papua New Guinea
1978	American Samoa*, Antigua and Barbuda*, Egypt, El Salvador, French Polynesia*, Ghana, Gibraltar, Guam*, Oman, Sierra Leone, St Lucia*, Vanuatu*, Yemen
1979	Algeria, Angola, China, Congo (Rep), Czechoslovakia, Djibouti*, Libya, Malta, Martinique, Mauritius*, Netherlands Antilles, Qatar, Sri Lanka, Sudan, Syria
1980	Costa Rica, Dominica*, Liberia, Madagascar, Pakistan, Uruguay
1981	Bangladesh, Belize*, Brunei, Congo (DR), Fiji*, Guadeloupe, New Caledonia*, Romania, Samoa*, Seychelles*, Togo, Tunisia, Turkey, Venezuela
1982	Ascension Island, Austria*, Gambia, Mauritania, Montserrat*, Myanmar, Tuvalu*
1983	Bermuda*, Ethiopia, Guinea, US Virgin Islands*
1985	Senegal
1992	Latvia, Reunion
1993	Estonia
1995	Lithuania
1998	Cayman Islands*
2000	Cuba, Vietnam
2001	French Guiana
2002	Georgia, Kiribati
2003	Cambodia

Non-adopters by 2008: Albania, Cabo Verde, Gabon, Solomon Islands, Somalia, and São Tomé e Principe.

New countries which already had a container port when they became independent: (independence year is in parenthesis). Former Yugoslavia: Croatia (1992), Montenegro (2007), Serbia (2007), Slovenia (1992), and the Federal Republic of Yugoslavia (2007); Former Czechoslovakia: Slovak Republic (1993); Former USSR: Ukraine and Russia (1992).

Countries with new territory where a container port already existed: Eritrea

(1994, from Ethiopia) and Namibia (1995, from South Africa).

Note: Countries with a * were not included in the estimations. These countries are either small states that were not independent in the sample period, small states for which the IMF does not report trade data, or countries with no data for usage of containerization.

Missing data for containerized and general cargo trade: I imputed missing values for containerized trade at each port using the following regression:

$$\text{containerized trade}_{it} = \beta_{0i} + \beta_{1i}\{\text{TEUs}\}_{it} + \beta_{2i}t + \epsilon_{it} \ , \qquad \text{(A.1)}$$

where subscript i indicates port. I estimate this regression using OLS and a Bayesian approach based on Markov chain Monte Carlo (MCMC) simulation. For most ports, R-squares are reasonably high, and MCMC predictions are not significantly dissimilar from OLS. Of all predictions generated by both estimation techniques, I consider only those for which the difference between the OLS and MCMC predictions is smaller than one standard deviation of all available data for each port. For these valid predictions, my imputed value is the average of the OLS and MCMC predictions. This criteria generates a total of 326 imputed values, which is 2.1 percent of the entire dataset.

To impute missing values for general cargo trade, I first combine data for total trade, general cargo trade, and the share of general cargo in total trade, whichever is available. Then, I estimate the following regression using OLS and MCMC:

$$\begin{aligned} \text{share general cargo}_{ijt} \ = \ & \beta_0 + \beta_1\{\text{industry share of GDP}\}_{jt} \\ & +\beta_2\{\text{total trade}\}_{ijt} + \beta_3\{\text{share oil exports}\}_{jt} \\ & +\beta_4\{\text{share oil imports}\}_{jt} + \beta_5 t + \theta_j + \theta_t + \epsilon_{ijt} \ , \qquad \text{(A.2)} \end{aligned}$$

where subscript i indicates port, subscript j indicates country, and subscript t indicates year. To select valid predictions, I use the same selection criteria as above—I consider only those predictions for which the difference between OLS and MCMC is smaller than one standard deviation of all available data for each port. This strategy generates 451 imputed values, which is 2.9 percent of the entire dataset.

A2 Maritime Distances

I used Reynolds and Caney (2010) to calculate maritime distances between ports. This book is the standard reference publication for maritime shipping operators. It contains lookup tables with the shortest or most economical distance between most ports and terminals worldwide.

The distance between any two countries is the minimum maritime distance between all their ports. For port-pairs not listed in Reynolds and Caney (2010), I use the closest international hub as a connection point. I consider 8 international hubs; they are ports that *Containerisation International* yearbooks ranked in the top 5 by volume of container traffic in 1975, 1983, or 2000: Busan (South Korea), Hong Kong (Hong Kong SAR), Kaohsiung (Taiwan), Kobe (Japan), New York (USA), Oakland (USA), Rotterdam (Netherlands), and Singapore (Singapore). While, ideally, international hubs are the largest ports regardless of cargo type, the fact that many of these container hubs are also large hubs for bulk trade makes this a fairly good set of international hubs.

A3 Other Variables

Below is information on the data sources and construction of other variables used in the paper.

Area: in square km, from Central Intelligence Agency (1990) and 2011.

Banking crisis dummy: Episodes of systematic banking crisis as defined in Laeven and Valencia (2010).

Bilateral Trade: in U.S. dollars, from IMF (2002a) and IMF (2013).

Consumer Price Index: Annual averages, from Federal Reserve Economic Data (FRED) series CPIAUCNS (Consumer Price Index for All Urban Consumers: All Items).

Distance to network: Trade-weighted average maritime distance to all countries in the container network. I use the shortest distance between any two countries. Port-to-port maritime distances are from Reynolds and Caney (2010). The trade weights are 5-year averages of bilateral trade shares, in real dollars, from IMF (2013).

Executive Constraints: constraints on the decision-making powers of chief executives, scaled from 1 to 7, 1950–2008, from Polity IV (www.systemicpeace.org).

GDP: from Heston et al. (2011).

Income groups: I follow World Bank income classifications, based on per capita income in 1992. Low to medium-low income countries have per capita income below $2,695 and high to medium-high income countries have income above $2,696.

Length of coastline: in km, from Central Intelligence Agency (1990) and 2011.
Length of railway lines and paved roads: in kilometers, from Canning (1998).
Oil trade: from *World Development Indicators* (2011).
Oil exporter: country with oil exports of more than 80 percent of total exports, from *World Development Indicators* (2011).
Population: from Heston et al. (2011).
Trade openness: Total imports and exports over GDP, from IMF (2013) and Heston et al. (2011).
Ethnic and linguistic fractionalization: one minus the Herfindahl index of ethnic or linguistic group shares, from Alesina et al. (2003).

B Theory Appendix

B1 Firms operating profits

The operating profits of a firm in country j with input parameter a (productivity $1/a$) from exporting variety k to country i are

$$\pi^k_{ij,t}(a) = \tilde{p}^k_{ij,t}(a)x^k_{ij,t} - a\tau_{ij}x^k_{ij,t} - f_{j,t} \ , \tag{B.1}$$

where $\tilde{p}^k_{ij,t}(a)$ is the consumer price of variety k in country i and $x^k_{ij,t}$ is the demand for variety k that results from country i's consumers' utility maximization (equation 2 in the text):

$$x^k_{ij,t} = \left(\tilde{p}^k_{ij,t}\right)^{-\epsilon} {P_{i,t}}^{\epsilon-1} Y_{i,t} \ . \tag{B.2}$$

Since the firm is monopolistically competitive, it maximizes profits taking the aggregate price

$$P_{i,t} = \left[\int_{k\in\Omega_{i,t}} (\tilde{p}^k_{i,t})^{1-\epsilon} dk\right]^{\frac{1}{1-\epsilon}} \tag{B.3}$$

as given. As a result, it sets its price as a markup over marginal costs:

$$\tilde{p}^k_{ij,t}(a) = \frac{a}{\alpha}\tau_{ij} \ , \tag{B.4}$$

where $\alpha = (\epsilon - 1)/\epsilon$. Using this equilibrium price in (B.1) and (B.2), country j's firm optimal operating profits from selling in country i can be expressed as

$$\pi_{ij,t}(a) = (1-\alpha)\left(\frac{a\tau_{ij}}{\alpha P_{i,t}}\right)^{1-\epsilon} Y_{i,t} - f_{j,t} \ . \tag{B.5}$$

Note that, since the fixed costs from selling domestically are zero, the firm's operating profits from selling in the domestic market are always positive. Also, since each firm can be identified by both its variety and its productivity parameter, I dropped the superscripts k.

B2 Productivity cutoffs

While all firms sell in the domestic market, not all firms sell in the foreign market. Only firms with productivity above a cutoff find it profitable to export. For country j's firms selling in country i, this cutoff is implicitly determined by the following zero-profit condition:

$$\begin{aligned} & \pi_{ij,t}(a^b_{ij,t}) = 0 \qquad \forall j \neq i \\ \Leftrightarrow \quad & (1-\alpha)\left(\frac{a^b_{ij,t}}{\alpha P_{i,t}}\tau^b_{ij}\right)^{1-\epsilon} Y_{i,t} - f^b_{j,t} = 0 \\ \Leftrightarrow \quad & (a^b_{ij,t})^{1-\epsilon} = \frac{f^b_j}{(\tau^b_{ij})^{1-\epsilon}} \frac{\alpha^{1-\epsilon}}{1-\alpha} \frac{P^{1-\epsilon}_{i,t}}{Y_{i,t}} \ . \end{aligned} \tag{B.6}$$

For productivity levels between $(a^b_{ij,t})^{1-\epsilon}$ and $(a^c_{ij,t})^{1-\epsilon}$, exporters have positive operating profits from exporting using breakbulk that are higher than the operating profits from exporting using containerization. The cutoff $(a^c_{ij,t})^{1-\epsilon}$ is determined by equating the operating profits from exporting using breakbulk shipping and the operating profits from exporting using containerized shipping:

$$\begin{aligned} (1-\alpha)\left(\frac{a^c_{ij,t}}{\alpha P_{i,t}}\tau^b_{ij}\right)^{1-\epsilon} Y_{i,t} - f^b_{j,t} &= (1-\alpha)\left(\frac{a^c_{ij,t}}{\alpha P_{i,t}}\tilde{\tau}^c_{ij}\right)^{1-\epsilon} Y_{i,t} - f^c_{j,t} \\ \Leftrightarrow \quad (a^c_{ij,t})^{1-\epsilon} &= \frac{f^c_{j,t} - f^b_j}{(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}} \frac{\alpha^{1-\epsilon}}{1-\alpha} \frac{P^{1-\epsilon}_{i,t}}{Y_{i,t}} \ . \end{aligned} \tag{B.7}$$

Firms with productivity above this cutoff $(a^c_{ij,t})^{1-\epsilon}$ have higher operating profits from exporting using containerization than from exporting using breakbulk.

B3 Revenues, costs, and exports

The difference in firm revenues between shipping exports with containerization and shipping exports with breakbulk is

$$
\begin{aligned}
R_t^{(c-b)} \equiv R^c - R^b &= \tilde{p}^c_{ij,t} x^c_{ij,t} - \tilde{p}^b_{ij,t} x^b_{ij,t} \\
&= \left(\frac{a}{\alpha}\tilde{\tau}^c_{ij}\right)^{1-\epsilon} {P_{i,t}}^{\epsilon-1} Y_{i,t} - \left(\frac{a}{\alpha}\tau^b_{ij}\right)^{1-\epsilon} {P_{i,t}}^{\epsilon-1} Y_{i,t} \\
&= \left(\frac{a}{\alpha}\right)^{1-\epsilon} \left[(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}\right] P_{it}^{\epsilon-1} Y_{it} \ . \qquad \text{(B.8)}
\end{aligned}
$$

This revenue difference is a linear function of $a^{1-\epsilon}$, and since $\epsilon > 1$ and $\tilde{\tau}^c_{ij} < \tau^b_{ij}$, the slope $\alpha^{\epsilon-1}\left[(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}\right] P_{it}^{\epsilon-1} Y_{it}$ is strictly positive.

Similarly, the difference in firm costs between shipping with the two technologies is

$$
\begin{aligned}
C_t^{(c-b)} \equiv C_t^c - C_t^b &= a\tilde{\tau}^c_{ij} x^k_{ij,t} + f^c_{j,t} - \left(a\tau^b_{ij} x^k_{ij,t} + f^b_j\right) \\
&= (f^c_{j,t} - f^b_j) + a^{1-\epsilon}\alpha^{\epsilon}\left[(\tilde{\tau}^c_{ij})^{1-\epsilon} - (\tau^b_{ij})^{1-\epsilon}\right] P_{it}^{\epsilon-1} Y_{it} \ . \qquad \text{(B.9)}
\end{aligned}
$$

This cost difference is also a linear function of $a^{1-\epsilon}$. Relative to the revenue difference above, it has a larger intersect, $(f^c_{j,t} - f^b_j) > 0$, and since $\epsilon > 1$ and $0 < \alpha < 1$, its slope is smaller.

In this appendix, I also show that the difference in firms' export volume between using containerized shipping and breakbulk is positive as long as containerization's shipping costs (net of port usage fees) are smaller than breakbulk's:

$$
\begin{aligned}
x^c_{ij}(a) - x^b_{ij}(a) &= \left(\frac{a}{\alpha}\tilde{\tau}^c_{ij}\right)^{-\epsilon} {P_{i,t}}^{\epsilon-1} Y_{i,t} - \left(\frac{a}{\alpha}\tau^b_{ij}\right)^{-\epsilon} {P_{i,t}}^{\epsilon-1} Y_{i,t} \qquad \text{(B.10)} \\
&= \left(\frac{a}{\alpha}\right)^{-\epsilon} \left[(\tilde{\tau}^c_{ij})^{-\epsilon} - (\tau^b_{ij})^{-\epsilon}\right] P_{it}^{\epsilon-1} Y_{it} \qquad \text{(B.11)} \\
&> 0 \quad \text{if} \quad \tilde{\tau}^c_{ij} < \tau^b_{ij} \ . \qquad \text{(B.12)}
\end{aligned}
$$

B4 Share of containerized trade

Use the distribution function in equation (16) to rewrite equation (15) as

$$T^c_{j,t} = \sum_{l \neq j}^{M-1} A_{l,t} \left(\frac{\tilde{\tau}^c_{lj}}{\alpha} \right)^{-\epsilon} \frac{\kappa}{\kappa - \epsilon + 1} \left[\frac{(a^c_{lj,t})^{\kappa-\epsilon+1}}{a^\kappa_H} P^{\epsilon-1}_{l,t} Y_{l,t} + \frac{(a^c_{jl,t})^{\kappa-\epsilon+1}}{a^\kappa_H} P^{\epsilon-1}_{j,t} Y_{j,t} \right] . \quad \text{(B.13)}$$

Plugging containerization's productivity cutoffs $a^c_{lj,t}$ and $a^c_{jl,t}$ into this equation and simplifying yields the following expression for containerized trade:

$$\begin{aligned} T^c_{j,t} &= D \left(f^c_{j,t} - f^b_j \right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \sum_{l \neq j}^{M-1} A_{l,t} (\tilde{\tau}^c_{lj})^{-\epsilon} \left[(\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon} \right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}} \\ & \left[P^\kappa_{l,t} Y^{\frac{\kappa}{\epsilon-1}}_{l,t} + \left(\frac{f^c_{l,t} - f^b_l}{f^c_{j,t} - f^b_j} \right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y^{\frac{\kappa}{\epsilon-1}}_{j,t} \right], \end{aligned} \quad \text{(B.14)}$$

where $D = \kappa \alpha^{\kappa+2\epsilon-1} (1-\alpha)^{1/(\epsilon-1)} (a_H)^{-\kappa} / (\kappa - \epsilon + 1)$.

Similarly, total general cargo trade (containerized and breakbulk) can be expressed as

$$T^{cb}_{j,t} = \sum_{l \neq j}^{M-1} \left(\frac{\tau^b_{lj}}{\alpha} \right)^{-\epsilon} \frac{\kappa}{\kappa - \epsilon + 1} \left[\frac{(a^b_{lj,t})^{\kappa-\epsilon+1}}{a^\kappa_H} P^{\epsilon-1}_{l,t} Y_{l,t} + \frac{(a^b_{jl,t})^{\kappa-\epsilon+1}}{a^\kappa_H} P^{\epsilon-1}_{j,t} Y_{j,t} \right] . \quad \text{(B.15)}$$

Plugging breakbulk's productivity cutoffs $a^b_{lj,t}$ and $a^b_{jl,t}$ into this equation and simplifying yields the following expression for total general cargo trade:

$$T^{cb}_{j,t} = D \left(f^b_j \right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \sum_{l \neq j}^{M-1} (\tau^b_{lj})^{-\epsilon} (\tau^b_{lj})^{-\kappa+\epsilon-1} \left[P^\kappa_{l,t} Y^{\frac{\kappa}{\epsilon-1}}_{l,t} + \left(\frac{f^b_l}{f^b_j} \right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y^{\frac{\kappa}{\epsilon-1}}_{j,t} \right], \quad \text{(B.16)}$$

where $D = \kappa \alpha^{\kappa+2\epsilon-1} (1-\alpha)^{1/(\epsilon-1)} (a_H)^{-\kappa} / (\kappa - \epsilon + 1)$.

The share of containerized trade is the ratio of equations (B.14) and (B.16), which is equivalent to equations (17) through (19) in the text.

B5 Predictions of the model

In this section, I provide proofs for the predictions presented in Section III. Since the model is partial equilibrium, I abstract from aggregate-price effects. However, though taking these effects into account would reduce the magnitude of the partial derivatives presented below, the signs would remain unchanged.

Proof of Prediction 1

(A) Show that $\frac{\partial ST^c_{j,t}}{\partial f^c_{j,t}} < 0$.

$$\begin{aligned}\frac{\partial ST^c_{j,t}}{\partial f^c_{j,t}} &= \frac{\kappa-\epsilon+1}{1-\epsilon}\frac{\left(f^b_j\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}}}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}}\Bigg\{\left(f^c_{j,t}-f^b_j\right)^{\frac{\kappa}{1-\epsilon}}\sum_{l\neq j}^{M-1} A_{l,t}V^c_{lj,t} - \left(f^c_{j,t}-f^b_j\right)^{-1} P^\kappa_{j,t}Y^{\frac{\kappa}{\epsilon-1}}_{j,t} \\ &\quad \sum_{l\neq j}^{M-1} A_{l,t}(\tilde{\tau}^c_{lj})^{-\epsilon}\left((\tilde{\tau}^c_{lj})^{1-\epsilon}-(\tau^b_{lj})^{1-\epsilon}\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}}\left(f^c_{l,t}-f^b_l\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}}\Bigg\} \qquad \text{(B.17)}\\ &= \frac{\kappa-\epsilon+1}{1-\epsilon}\frac{\left(f^b_j\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}}}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}}\left(f^c_{j,t}-f^b_j\right)^{\frac{\kappa}{1-\epsilon}}\sum_{l\neq j}^{M-1} A_{l,t}(\tilde{\tau}^c_{lj})^{-\epsilon} \\ &\quad \left[(\tilde{\tau}^c_{lj})^{1-\epsilon}-(\tau^b_{lj})^{1-\epsilon}\right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}} P^\kappa_{l,t}Y^{\frac{\kappa}{\epsilon-1}}_{l,t} \qquad \text{(B.18)}\\ &< 0\ ,\end{aligned}$$

since $\epsilon > 1$, $\kappa > \epsilon - 1$, $\tilde{\tau}^c_{lj} < \tau^b_{lj}$, and $f^c_{j,t} > f^b_j\ \forall j, t$.

(B) Show that $\frac{\partial ST^c_{l,t}}{\partial f^c_{l,t}} < 0,\ \forall l \neq j : A_{l,t} = 1$.

$$\begin{aligned}\frac{\partial ST^c_{l,t}}{\partial f^c_{l,t}} &= \frac{\kappa-\epsilon+1}{1-\epsilon}\frac{\left(f^b_j\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}}}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}}P^\kappa_{j,t}Y^{\frac{\kappa}{\epsilon-1}}_{j,t}\sum_{l\neq j}^{M-1} A_{l,t}(\tilde{\tau}^c_{lj})^{-\epsilon} \\ &\quad \left[(\tilde{\tau}^c_{lj})^{1-\epsilon}-(\tau^b_{lj})^{1-\epsilon}\right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}}\left(f^c_{l,t}-f^b_l\right)^{\frac{\kappa}{1-\epsilon}}\Bigg\} \qquad \text{(B.19)}\\ &< 0\ \ \forall l\neq j : A_{l,t}=1\ ,\end{aligned}$$

since $\epsilon > 1$, $\kappa > \epsilon - 1$, $\tilde{\tau}^c_{lj} < \tau^b_{lj}$, and $f^c_{l,t} > f^b_l\ \forall l, t$.

Proof of Prediction 2

Show that $\frac{\partial ST^c_{j,t}}{\partial A_{l,t}} > 0,\ \forall l \neq j$.

$$\begin{aligned}\frac{\partial ST^c_{j,t}}{\partial A_{l,t}} &= \left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \frac{\sum_{l\neq j}^{M-1} V^c_{lj,t}}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}} \\ &> 0 \ ,\end{aligned} \tag{B.20}$$

since $f^c_{j,t} > f^b_j\ \forall j,t$, $V^c_{lj,t} > 0$, and $V^{cb}_{lj,t} > 0$.

Proof of Prediction 3

Show that the signs of $\frac{\partial ST^c_{j,t}}{\partial Y_{j,t}}$ and $\frac{\partial ST^c_{j,t}}{\partial Y_{l,t}}$ are ambiguous.

$$\frac{\partial ST^c_{j,t}}{\partial Y_{j,t}} = \left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \frac{\sum_{l\neq j}^{M-1} A_{l,t}\frac{\partial V^c_{lj,t}}{\partial Y_{j,t}}\ \sum_{l\neq j}^{M-1} V^{cb}_{lj,t} - \sum_{l\neq j}^{M-1} A_{l,t}V^c_{lj,t}\ \sum_{l\neq j}^{M-1}\frac{\partial V^{cb}_{lj,t}}{\partial Y_{j,t}}}{\left(\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}\right)^2} \ ,$$

where

$$\frac{\partial V^c_{j,t}}{\partial Y_{j,t}} = \frac{\kappa}{\epsilon-1}(\tilde{\tau}^c_{lj})^{-\epsilon}\left[(\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon}\right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}} \left(\frac{f^c_{l,t} - f^b_l}{f^c_{j,t} - f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y_{l,t}^{\frac{\kappa-\epsilon+1}{\epsilon-1}} > 0$$

and

$$\frac{\partial V^{cb}_{j,t}}{\partial Y_{j,t}} = \frac{\kappa}{\epsilon-1}(\tilde{\tau}^c_{lj})^{-\epsilon}(\tau^b_{lj})^{-\kappa+\epsilon-1}\left(\frac{f^b_l}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^\kappa_{j,t} Y_{l,t}^{\frac{\kappa-\epsilon+1}{\epsilon-1}} > 0 \ .$$

Similarly,

$$\frac{\partial ST^c_{j,t}}{\partial Y_{l,t}} = \left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \frac{\sum_{l\neq j}^{M-1} A_{l,t}\frac{\partial V^c_{lj,t}}{\partial Y_{l,t}}\ \sum_{l\neq j}^{M-1} V^{cb}_{lj,t} - \sum_{l\neq j}^{M-1} A_{l,t}V^c_{lj,t}\ \sum_{l\neq j}^{M-1}\frac{\partial V^{cb}_{lj,t}}{\partial Y_{l,t}}}{\left(\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}\right)^2} \ ,$$

where

$$\frac{\partial V^c_{j,t}}{\partial Y_{l,t}} = \frac{\kappa}{\epsilon-1}(\tilde{\tau}^c_{lj})^{-\epsilon}\left[(\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon}\right]^{\frac{\kappa-\epsilon+1}{\epsilon-1}} P^\kappa_{j,t} Y_{l,t}^{\frac{\kappa-\epsilon+1}{\epsilon-1}} > 0$$

and

$$\frac{\partial V^{cb}_{j,t}}{\partial Y_{l,t}} = \frac{\kappa}{\epsilon - 1}(\tilde{\tau}^c_{lj})^{-\epsilon}(\tau^b_{lj})^{-\kappa+\epsilon-1}P^{\kappa}_{j,t}Y_{l,t}^{\frac{\kappa-\epsilon+1}{\epsilon-1}} > 0 \ .$$

Therefore, the signs of $\partial ST^c_{j,t}/\partial Y_{j,t}$ and $\partial ST^c_{j,t}/\partial Y_{l,t}$ depend on the magnitude of the two terms in the numerators, which in turn depend on fixed and transportation costs of containerization and breakbulk across countries.

Proof of Prediction 4

Show that $\frac{\partial ST^c_{j,t}}{\partial \tilde{\tau}^c_{lj}} < 0 \ \forall l \neq j$.

$$\begin{aligned}
\frac{\partial ST^c_{j,t}}{\partial \tilde{\tau}^c_{lj}} \ &= \ \left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \frac{1}{\sum_{l\neq j}^{M-1} V^{cb}_{lj,t}} \sum_{l\neq j}^{M-1} A_{l,t} \Bigg\{ \Bigg[-\epsilon(\tilde{\tau}^c_{lj})^{-\epsilon-1} \left((\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon}\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}} \\
&\quad + \frac{\kappa-\epsilon+1}{(\epsilon-1)(1-\epsilon)}(\tilde{\tau}^c_{lj})^{-2\epsilon}\left((\tilde{\tau}^c_{lj})^{1-\epsilon} - (\tau^b_{lj})^{1-\epsilon}\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}-1} \Bigg] \\
&\quad \left[P^{\kappa}_{l,t}Y_{l,t}^{\frac{\kappa}{\epsilon-1}} + \left(\frac{f^c_{l,t} - f^b_l}{f^c_{j,t} - f^b_j}\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} P^{\kappa}_{j,t}Y_{j,t}^{\frac{\kappa}{\epsilon-1}} \right] \Bigg\} \\
&< \ 0 \ ,
\end{aligned} \tag{B.21}$$

since $\epsilon > 1$, $\kappa > \epsilon - 1$, $\tilde{\tau}^c_{lj} < \tau^b_{lj}$, and $f^c_{j,t} > f^b_j \ \forall j, t$.

C Additional Tables and Figures

TABLE C.1. **Usage of containerization: robustness checks**

	(1)	(2)	(3)
Length railway lines (1M Km)	15.15**	64.25	71.08
	(2.81)	(51.30)	(62.00)
Length paved roads (1M Km)	-0.01	0.14	0.20
	(0.28)	(0.20)	(0.17)
Log real GDP	0.21	0.23	0.44
	(0.24)	(0.26)	(0.31)
Container network size		4.86**	8.76*
		(1.33)	(3.33)
Container network size, t-5	1.23**		
	(0.40)		
Distance to trade network	-0.06	-0.63+	-0.81
	(0.47)	(0.38)	(0.48)
Network log real GDP	0.07**	0.04+	0.04
	(0.02)	(0.02)	(0.04)
Network length railways	8.58	4.54	1.27
	(6.85)	(6.33)	(6.96)
Network length paved roads	-0.46	-0.26	-0.14
	(0.34)	(0.36)	(0.37)
Observations	1643	1483	878
R^2	0.69	0.72	0.68
Nr. countries	74	71	46
Country f.e.	Yes	Yes	Yes
Year adoption f.e.	Yes	Yes	Yes
Sub-sample		world trade share $< 10\%$	Year adoption > 1970

Note: The dependent variable is the share of containerized shipping, in logs. All explanatory variables are lagged one year, except the instrument. Controls (not shown): constant, number of years since adoption, log population, share in world trade, dummy for oil exporter, dummy for banking crisis, and dummy for the period when the Suez Canal was closed. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

TABLE C.2. **Usage of containerization and neighbor's adoption**

	(1)	(2)	(3)
Containerized neighbors	0.93*		0.87*
	(0.43)		(0.43)
Containerized non-neighbors		2.85**	2.57**
		(0.85)	(0.90)
Length railway lines (1M Km)	13.39**	15.34**	14.90**
	(2.33)	(3.02)	(2.86)
Length paved roads (1M Km)	-0.12	-0.02	-0.13
	(0.19)	(0.30)	(0.24)
Log real GDP	0.33	0.25	0.31
	(0.25)	(0.24)	(0.24)
Distance to trade network	-0.16	-0.19	-0.33
	(0.46)	(0.44)	(0.43)
Network log real GDP	0.07**	0.05*	0.04+
	(0.02)	(0.02)	(0.02)
Network length railways	9.41	7.63	9.53
	(6.34)	(6.94)	(6.40)
Network length paved roads	-0.32	-0.31	-0.20
	(0.35)	(0.35)	(0.35)
Observations	1643	1643	1643
R^2	0.69	0.68	0.70
Nr. countries	74	74	74
Country f.e.	Yes	Yes	Yes
Year adoption f.e.	Yes	Yes	Yes

Note: The dependent variable is the share of containerized shipping, in logs. **Neighbors are defined as countries that share a common border.** All explanatory variables are lagged one year. Controls (not shown): constant, number of years since adoption, log population, share in world trade, dummy for oil exporter, dummy for banking crisis, and dummy for the period when the Suez Canal was closed. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

TABLE C.3. **Usage of containerization and neighbor's adoption**

	(1)	(2)	(3)
Containerized neighbors	0.52		0.43
	(0.43)		(0.43)
Containerized non-neighbors		2.32**	2.11**
		(0.63)	(0.64)
Length railway lines (1M Km)	13.23**	14.51**	14.06**
	(2.34)	(2.66)	(2.53)
Length paved roads (1M Km)	-0.09	0.02	-0.06
	(0.22)	(0.28)	(0.25)
Log real GDP	0.30	0.25	0.28
	(0.25)	(0.25)	(0.25)
Distance to trade network	-0.12	-0.21	-0.30
	(0.44)	(0.45)	(0.43)
Network log real GDP	0.08**	0.05*	0.05*
	(0.02)	(0.02)	(0.02)
Network length railways	9.71	6.72	8.74
	(6.64)	(6.74)	(6.43)
Network length paved roads	-0.40	-0.32	-0.28
	(0.35)	(0.35)	(0.35)
Observations	1643	1643	1643
R^2	0.68	0.68	0.69
Nr. countries	74	74	74
Country f.e.	Yes	Yes	Yes
Year adoption f.e.	Yes	Yes	Yes

Note: The dependent variable is the share of containerized shipping, in logs. **Neighbors are defined as countries that share a common border and are within 500 miles of each other.** All explanatory variables are lagged one year. Controls (not shown): constant, number of years since adoption, log population, share in world trade, dummy for oil exporter, dummy for banking crisis, and dummy for the period when the Suez Canal was closed. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

TABLE C.4. **Usage of containerization and neighbor's adoption**

	(1)	(2)	(3)
Containerized neighbors	0.57		0.40
	(0.36)		(0.33)
Containerized non-neighbors		2.85**	2.67**
		(0.86)	(0.80)
Length railway lines (1M Km)	13.34**	15.26**	14.92**
	(2.44)	(3.00)	(3.01)
Length paved roads (1M Km)	0.00	-0.01	-0.01
	(0.26)	(0.29)	(0.30)
Log real GDP	0.27	0.25	0.24
	(0.25)	(0.24)	(0.24)
Distance to trade network	-0.06	-0.20	-0.24
	(0.44)	(0.46)	(0.44)
Network log real GDP	0.08**	0.04*	0.04*
	(0.02)	(0.02)	(0.02)
Network length railways	7.88	8.20	8.52
	(6.50)	(6.85)	(6.62)
Network length paved roads	-0.43	-0.32	-0.31
	(0.35)	(0.35)	(0.35)
Observations	1643	1643	1643
R^2	0.68	0.69	0.69
Nr. countries	74	74	74
Country f.e.	Yes	Yes	Yes
Year adoption f.e.	Yes	Yes	Yes

Note: The dependent variable is the share of containerized shipping, in logs. **Neighbors are defined as countries that were in a colonial relationship at some point after 1945.** All explanatory variables are lagged one year. Controls (not shown): constant, number of years since adoption, log population, share in world trade, dummy for oil exporter, dummy for banking crisis, and dummy for the period when the Suez Canal was closed. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

TABLE C.5. **Adoption of containerization: 10-year horizon**

	(1)	(2)	(3)
Predicted log cont. trade 10yr	0.752*	1.232	1.712
	(0.314)	(23.614)	(256.833)
Log real GDP p.c.	1.218*	1.049	1.828
	(0.539)	(28.639)	(316.421)
Ethnic fractionalization	-0.291	-0.389	-0.339
	(2.723)	(9.948)	(575.228)
Linguistic fractionalization	2.153	2.929	4.279
	(2.146)	(68.359)	(588.360)
Executive contraints	0.014	-0.081	0.142
	(0.142)	(1.649)	(30.036)
Share of trade with USA		2.691	12.080
		(106.450)	(873.942)
Share of trade with AUS		-11.673	-18.372
		(2600.674)	(2007.249)
Share of trade with BEL		-0.112	4.635
		(724.892)	(3558.931)
Share of trade with NLD		-6.021	2.625
		(3494.577)	(4109.311)
Share of trade with GBR		4.369	8.252
		(304.761)	(1141.794)
Dummy 1956-1965	-3.347		
	(6.030)		
Dummy 1966-1974	-0.974	-0.706	-2.311
	(5.906)	(74.763)	(598.922)
Dummy 1975-1983	0.597	0.603	0.049
	(5.832)	(61.010)	(338.188)
Observations	228	196	185
Log-likelihood	-69.715	-62.520	-51.747
Sub-sample			Excl. oil exporters

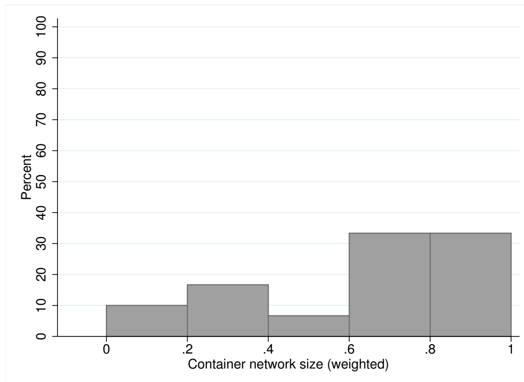
Note: The dependent variable is an indicator variable that takes the value one at the year of adoption and zero otherwise. For each country, I drop all observations corresponding to the years after adoption; that is, once a country adopts containerization, it is dropped from the estimation in the following years. Controls (not shown): log area, log length of coastline, log trade openness, and oil export share. Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

TABLE C.6. **Adoption of containerization: 50-year horizon**

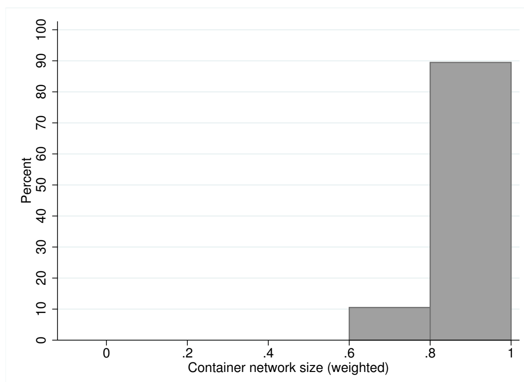
	(1)	(2)	(3)
Predicted log cont. trade 50yr	0.295	0.248	0.348
	(0.203)	(0.256)	(0.273)
Log real GDP p.c.	1.255**	1.011*	1.154*
	(0.359)	(0.443)	(0.494)
Ethnic fractionalization	-0.302	0.239	-0.028
	(1.778)	(2.426)	(2.517)
Linguistic fractionalization	1.673	1.199	1.268
	(1.376)	(1.984)	(1.995)
Executive contraints	0.018	-0.019	0.057
	(0.100)	(0.116)	(0.137)
Share of trade with USA		0.779	3.348
		(2.260)	(2.691)
Share of trade with AUS		-0.633	-4.288
		(15.064)	(15.864)
Share of trade with BEL		10.959	5.801
		(17.145)	(19.061)
Share of trade with NLD		-3.816	2.729
		(12.238)	(13.295)
Share of trade with GBR		2.677	4.086
		(3.329)	(3.545)
Dummy 1956-1965	-5.894		
	(5.135)		
Dummy 1966-1974	-2.652	-2.788	-3.432
	(5.088)	(5.341)	(5.371)
Dummy 1975-1983	-0.687	-0.731	-1.126
	(5.069)	(5.311)	(5.339)
Observations	483	384	367
Log-likelihood	-121.313	-116.086	-108.798
Sub-sample			Excl. oil exporters

Note: The dependent variable is an indicator variable that takes the value one at the year of adoption and zero otherwise. For each country, I drop all observations corresponding to the years after adoption; that is, once a country adopts containerization, it is dropped from the estimation in the following years. Controls (not shown): log area, log length of coastline, log trade openness, and oil export share. Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

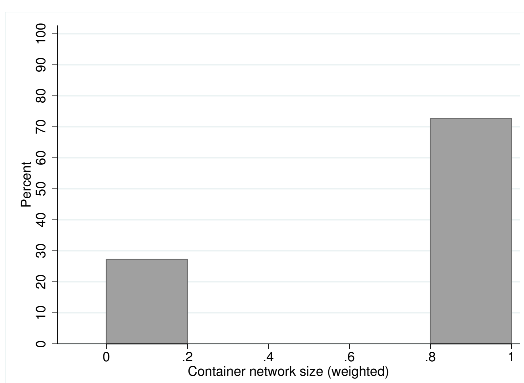
Figure C.1. **Histogram of the trade-weighted number of other adopters at the year when a country adopted containerization: different time periods**



(a) 1956-1970



(b) 1971-1983



(c) 1983-2008

Note: The weights are obtained using average bilateral trade shares for the previous five years, in real dollars. Sources: Author's dataset and IMF (2013).

FIGURE C.2. **Observed and expected usage of containerization**