Fixed Costs, Network Effects, and the International Diffusion of Containerization*

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Abstract

Containerization is one of the most important innovations affecting the conduct of international trade in the second half of the twentieth century. This paper analyzes its international diffusion and the factors that shaped today's container network. I construct a new dataset with information on the timing and intensity of adoption of containerization across countries. While adoption of container-port infrastructure follows an S-shaped curve, containerized trade moves more slowly and linearly. These findings guide the construction of a theoretical framework in which a transportation sector decides whether or not to build a container port. This decision is based on expectations about domestic and foreign firms' choices between two transportation technologies: breakbulk shipping and containerization. Changes in fixed costs and network effects generate the patterns observed in the data. I then estimate a two-step model derived from the theoretical framework. The empirical results, which are consistent with the theoretical predictions, show that fixed costs and network effects are the main determinants of usage of containerization. Fixed costs affect containerized trade as a result of the spread of leasing companies and changes in the domestic transportation network. Network effects operate through network size, network usage, and network income. With regards to adoption, my results show that expected future usage of containerization, institutions, a country's size in terms of trade and geographical area, and trade with Australia and the United Kingdom are the main determinants. Trade with the United States, surprisingly, has no effect. These results emphasize the importance of internal trade costs, the identity of countries' trade partners, and institutional barriers for technological diffusion, international trade, and countries' integration into the global economy.

*The views in this paper are those of the author and do not necessarily represent the views or policies of the Board of Governors of the Federal Reserve System or its staff.

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1 Introduction

> "The container made shipping cheap, and by doing so changed the shape of the world economy. (...) This new economic geography allowed firms whose ambitions had been purely domestic to become international companies, exporting their products almost as effortlessly as selling them nearby" (Levinson, 2008, pp. 2–3).

Stacked container boxes are ubiquitous: we see them in ports, in truck chassis on highways, and in train stations. Yet the role of these simple structures of steel or aluminum in the mechanics of the global economy often goes unnoticed. Before cargo was handled in containers, international trade was expensive and slow. As recently as the 1950s, shipping was highly labor-intensive, and automation was limited. Vessels could spend weeks at the dock while cargo was handled, piece by piece, by gangs of longshoremen. Since different kinds of goods, with different destinations, were shipped together in the hold, loading and unloading cargo was a complex procedure. Many items were lost or damaged.[1]

This all changed in the late 1950s with the advent of containerization. Instead of gangs of longshoremen loading thousands of loose items at the dock, a container could be filled with cargo far away from the dock, moved to the port, and then hoisted onto the ship using specialized cranes. Unloading was similarly simplified. Ships' time in port was greatly reduced. Loss, pilferage, and damage almost disappeared. Shipping became dramatically easier and faster.[2]

Today, containers filled with goods quickly move between warehouse, ship, train, and truck. They are the central piece of a complex global supply chain, with different stages of production located in various parts of the world. The IMF's *World Economic Outlook* called containers one of the "most important technological breakthroughs of the past fifty years" (International Monetary Fund, 2002, p. 116).

Despite the importance of containerization in 20th century globalization, an economic analysis of its diffusion is lacking. In this paper, I construct a new and comprehensive dataset on containerization's international diffusion. The dataset consists of information on worldwide adoption and usage of containerization for the entire period from the inaugural container journey in 1956 up to the present. I use this dataset, together with statistical and narrative evidence, to document and characterize the diffusion of containerization. I identify four phases: innovation and early adoption (1956–1965), internationalization (1965–1974), worldwide adoption and intensification of use (1975–1983), and late adoption and growth of usage (1984–2008).

Two stylized facts emerge from this historical pattern of diffusion:

1. the adoption of port infrastructure follows an S-shaped curve (consistent with the innovation literature[3]), and

2. the use of containerization in international trade moves much more slowly and has a more linear trend than the adoption of port infrastructure.[4]

[1] See Ignarski (2006) and Woodman (1988) for vivid descriptions of the shipping business prior to containerization.

[2] Levinson (2008), chapter 1, provides a window onto the intense and fast-paced activity of a container port.

[3] For example, Griliches (1957), Saloner and Shepard (1995), and Battisti and Stoneman (2003).

[4] Only after 50% of the countries in my sample had already built at least one container port did usage of containerization take off, around 1975.

I then provide theoretical and empirical analyses of the determinants of adoption and usage of containerization. The theoretical model focuses on firms' choices between two transportation technologies (containerization and breakbulk)[5] and on the decision by the country's transportation sector to construct, maintain and operate a container port. The model predicts that adoption, which follows an S-shaped path, is determined in particular by the cost of adoption and predicted containerized trade. Fixed costs and network effects determine firms' usage of containerization and therefore the share of trade that is containerized. These predictions are consistent with the broad patterns we see in the data and motivate the empirical analysis. Using a two-step approach suggested by the model, I investigate the determinants of adoption and usage of containerization. The empirical results show that fixed costs and network effects are the main determinants of usage of containerization. Fixed costs affect containerized trade as a result of the spread of leasing companies and changes in the domestic transportation network. Network effects operate through network size, network usage, and network income. Moreover, while the domestic transportation network matters more for high-income countries, growth in container leasing has a stronger effect on containerized trade in low-income countries. Network size matters equally for high- and low-income countries, but the effect of network usage is stronger in low-income countries than in high-income countries. With regards to adoption, I find that expected future usage of containerization, institutions, a country's size in terms of trade and geographical area, and trade with Australia and the United Kingdom are the main determinants. Trade with the United States, surprisingly, has no effect. Also, the impact of expected future containerized trade is very strong, regardless of the time-horizon used: five, twenty, or even fifty years.

My paper contributes to three literatures, those concerned with economic history, international trade, and innovation. First, the diffusion of containerization is one of the most important yet understudied aspects of 20th century globalization. Other technological improvements which were essential features of the 19th and early 20th centuries, such as the railroad (Fogel, 1964, Atack, Bateman, Haines, & Margo, 2010), the steamship (North, 1958), and the refrigerated car (Kujovich, 1970), have received fair attention in the economic history literature, from the perspectives of both their economic impact and their historical development. This paper provides an in-depth analysis of another and more recent technology, which transformed the entire economics of shipping in the second half of the 20th century and became an essential piece of our globalized world.

Second, the international trade literature has shown that transport costs are a major determinant of trade. They play a central role in explaining trade patterns and are still a significant barrier to trade in many countries.[6] For example, Estevadeordal, Frantz, and Taylor (2003) provide evidence linking declines in shipping costs to the growth in trade in the period 1870–1913. Hummels (2001) shows direct and indirect evidence on trade barriers and finds that measured

[5] I consider only trade in containerizable goods, i.e., general cargo trade. General cargo comprises a large variety of goods, including both manufactured and semi-manufactured goods, but it does not include bulk goods such as oil, fertilizers, ore, and grain. It can be shipped either in containers or breakbulk (breakbulk refers to transporting general cargo goods in the ship's hold, packed in cartons, bags, bales, or pallets, instead of in containers). (Sources: Institute of Shipping Economics and Logistics, 2008 and U.S. Department of Transportation, 2008)

[6] See Anderson and Wincoop (2004) for a detailed survey on the effects of different trade costs on trade flows.

trade costs, such as tariffs and freight, are the main channel through which trade barriers affect trade volumes. Since changes in transportation technology impact transportation costs and ultimately trade patterns, understanding the diffusion of new transportation technologies such as containerization is crucial for making sense of the rapid decline in transportation costs and the rise in trade volumes since 1950.[7] In addition, by identifying the main determinants of the international diffusion of containerization, my work not only allows a better understanding of the role of trade in the diffusion of containerization, but it also helps guide future research on the reverse effect, the impact of containerization on trade.

Finally, my research contributes to the literature on the diffusion of innovations, in particular at the international level. In a recent survey of the literature, Stoneman and Battisti (2010) observe that there are very few international studies of technology diffusion, primarily because of the limited availability of rich datasets with comparable international data.[8] My work fills this gap by constructing a dataset with extensive cross-country data for an important innovation. In addition, I investigate the role of network effects; that is, whether and how the use of containers in one country affects its use in other countries.[9]

Understanding how containerization developed and diffused is important for comprehending our globalized world; in particular, it is important for understanding how cross-country lags in the adoption of transportation technology interact with countries' integration into the global economy.

The remainder of the paper is structured as follows. Section 2 describes the dataset and the historical pattern of diffusion. Section 3 presents the theoretical framework which motivates the two-step estimation presented in Section 4. Section 4 analyses the determinants of adoption and usage of containerization and presents robustness checks. Section 5 concludes.

2 History of Containerization

2.1 The Dataset

I assemble historical data on the adoption and usage of containerization for the entire period 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[10] and the share of trade that is containerized.

Since ports are the primary nodes of the world shipping network and because of the im-

[7] In addition, Obstfeld and Rogoff (2000) argue that trade costs (including transport costs but also other trade barriers) are key to understanding the "six major puzzles" in international macroeconomics.

[8] A recent exception is the work by Comin and Hobijn, which uses an extensive dataset covering the diffusion of many technologies in a large set of countries over 200 years (however, coverage is incomplete, especially during the introductory phases). In Comin and Hobijn (2004), they use this dataset to study cross-country diffusion of about twenty technologies in twenty-three countries, and in Comin and Hobijn (2010), they develop a model to explain the effect that cross-country differences in the timing of adoption have on total factor productivity (TFP). They estimate the model using 15 technologies in 166 countries.

[9] The paucity of studies that address network effects at the country level is yet another limitation of current literature that was pointed out by Stoneman and Battisti (2010).

[10] Defined as the year when the first container port is constructed.

portance of maritime transportation in global freight trade,[11] I concentrate on traffic passing through ports, omitting that which passes through inland depots. In order to extend my dataset further, however, I include river as well as sea ports. Therefore, my sample excludes only landlocked countries that have no access to navigable inland waterways.

The three main sources of data are *Containerisation International Yearbook*, *Shipping Statistics Yearbook*, and *Lloyd's Ports of the World*. In addition, I collected data from port websites and requested data directly from port authorities.[12] 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 (*Annual Report*, 1996). There are also ports in my dataset which have no available data on total and containerized trade.[13] My final dataset contains the year of adoption for 147 countries and the share of containerized trade for 98 of these.

After collecting all available data for the ports in my dataset, there were still some gaps: 5% of containerized trade and 8.7% of general cargo trade were missing. I explain my strategy for dealing with these missing values and describe the resulting augmented dataset in Appendix D. This section also includes an explanation of how I aggregate port-level data to obtain each country's share of containerized general cargo trade.

2.2 Four Stages of Diffusion

Figure 1 depicts the two components of containerization diffusion: adoption and usage. The solid line is the share of countries (out of a total of 147) that have adopted containerization (i.e., they have built container-port infrastructure), while the dashed line is the average share of containerized trade (out of a total of 98 countries). The values shown in Figure 1(a) are unweighted averages of the countries in the sample. We see that adoption of containerization follows an S-shaped curve while usage of containerization moves more slowly and linearly. In Figure 1(b) the averages are weighted by each country's trade share. While accounting for countries' trade shares generates faster diffusion (since the first adopters are countries with large trade shares), the shape of both curves remains largely unchanged. Figure 1(c) compares adoption at the port level with adoption at the country level (there are 701 ports in the dataset). Once more, the logistic pattern of adoption is still present.

Building on the shape of the diffusion curves generated by the data, as well as on historical and anecdotal sources, we can divide the whole period into four stages in which adoption and usage exhibit different behaviors.[14]

(i) 1956–1965: innovation and early adoption

(ii) 1966–1974: internationalization

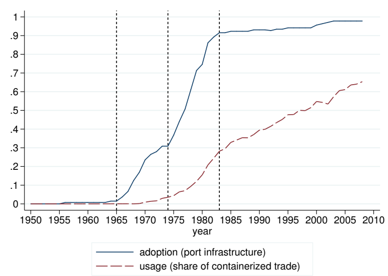
[11] Despite the recent growth in air transport, especially as regards value to weight, maritime shipping is still the dominant mode of transportation, accounting for 75% of world trade by volume in 2006 (Mandryk, 2009).

[12] See appendices A and B, and C for detailed information about these sources, coding rules, and country coverage.

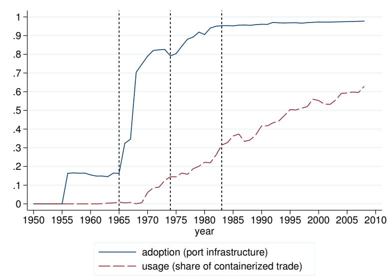
[13] These are mainly the smaller ports which most probably have also smaller shares of containerized trade. Their omission is likely to cause a small upward bias in my measure of a country's share of containerized trade, but given the small size of the ports that are omitted, I believe that it does not affect my results.

[14] These four stages are delineated in Figure 1 by the three vertical lines; the years I use as period boundaries are approximate. See Table 1 for descriptive statistics of each period.

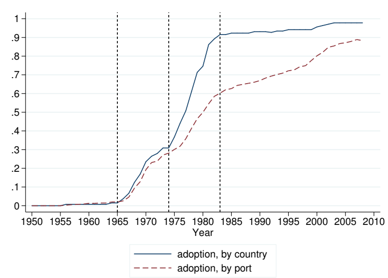
Figure 1: Diffusion of containerization



(a) Unweighted averages



(b) Weighted averages



(c) Port level vs. country level

(iii) 1975–1983: worldwide adoption and intensification of use

(iv) 1984–2008: late adoption and growth of usage

Table 1: The diffusion of containerization over time

	1956–1965	1966–1974	1975–1983	1984–2008
Adoption:				
New adoptions	2	43	86	17
New adoptions per year	0.2	5.4	10.8	0.7
Cumulative share of adoptions	1.3	30.2	87.9	99.3
Usage:				
Average share	0.1	3.5	28.7	65.5
Average annual change in share		0.3	1.6	1.5

The first period starts in 1956, when Malcom McLean sent a converted World War II tanker filled with fifty-eight truck trailers from Newark, NJ to Houston, TX.[15] In Newark, the trailers

[15]The ship was equipped with on-board cranes to make it self-sufficient.

were filled with cargo not at the dock but at the shippers' inland warehouses, loaded onto trucks that moved them to the dock, and lifted by crane onto the ship. At the other end, in Houston, fifty-eight trucks "haul[ed the boxes] to their destinations" (Levinson, 2008, p. 1). This idea was not original; there are many historical accounts of earlier attempts to put freight into container boxes. But, as Marc Levinson points out, "those earlier containers did not fundamentally alter the economics of shipping and had no wider consequences" (Levinson, 2008, p. 53). McLean's did.[16] They were part of a new method of transporting goods that affected the whole shipping industry: road, rail, water, and air. They challenged the traditional breakbulk methods and transformed the centuries-old, slow, and labor-intensive process of port-to-port shipping into a radically new system of intermodal door-to-door shipping: containerization.

There were many advantages afforded by containerization. Ships' time in port was dramatically reduced.[17] Containerization involved fewer contracts and was more reliable; furthermore, by reducing the risk of losses, pilferage, and damage, it cut down insurance costs. Since container ships were larger and faster than conventional ships, they not only lowered sailing times, but also generated economies of scale. Containerization largely reduced the need for longshoremen, bringing substantial savings on wages (although not without strong opposition of labor unions worldwide). While extensive quantitative data on these various costs are not available, there are abundant anecdotal reports and localized studies corroborating these facts. 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). Ross (1970) cites industry estimates indicating that "it would take 126 men 84 hours each, or a total of 10,584 man-hours, to discharge and load about 11,000 tons of cargo aboard a conventional ship. The same amount of cargo on a container vessel can be handled by 42 men working 13 hours each or a total of 546 man hours" (Ross, 1970, p. 400). A similar estimate was presented in 1974 by Clifford O'Hara, Director of Port Commerce of the Port Authority of New York and New Jersey:[18] 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).

Given these advantages and simplicity of the technology, why did it take so long to develop containerization? Three convergent developments that occurred in the US in the first half of the 20th century provide an answer. While companies were sending small shipments of cargo across the country or overseas, carrying them in a big metal box was not economically optimal. These small shipments would have to be consolidated with others in order to fill the container, and therefore moving goods as loose cargo in trucks, boxcars, and the holds of breakbulk ships was a more viable business. It was only when the nature of retailing and wholesaling changed, starting in the 1920s, that organizing production to fill an entire trailer or container made economic sense. The transition from small neighborhood retailers to large companies that dominated retailing and wholesaling made shipping of large quantities of goods more practical. The second

[16] The engineer behind McLean's vision about container shipping was Keith Tantlinger. He developed most of the technology that allows a shipping container to move between land and ship, for example, the corner fitting and twist-lock systems.

[17] Time in port was the largest and most important cost of running a vessel at the time.

[18] Previously the Port of New York Authority.

development was in land transportation. In the early 1950s, US railroads began to carry truck trailers in flatcars, a service they called "piggyback." Over longer distances, running a train was cheaper than running a truck (because of labor and fuel costs), and since rail rates were lower for full trailer loads, freight forwarding companies started to consolidate smaller shipments (Levinson, 2008, pp. 150–159). Furthermore, the smaller truck trip between the train and the final destination was also facilitated by the concurrent construction of the Interstate Highway System. Finally, US domestic maritime shipping was protected from foreign competition by legislation dating back to the 1920s. The Jones Act required that all goods transported by water between US ports be carried in US-flag ships with American crews.[19] Consistent with Schumpeterian models of innovation, this context of imperfect competition in the first half of the 20th century was the optimal market environment to generate innovation.[20] Moreover, because US labor costs were very high, these new technologies were likely to be labor-saving, as was the case with containerization.

Despite the simplicity and obvious attractions of this new technology, between the late 1950s and early 1960s containerization remained exclusively American. Moreover, there were only two shipping companies using containers (McLean's Pan-Atlantic on the east coast and Matson on the west coast), and less than 10 ports – along both US coasts and in Puerto Rico – had been adapted to the new technology. The large initial capital outlay (in containers, chassis, forklifts, ships, and cranes) and uncertainty about the future (for instance, containers' ability to radically reduce transportation costs and their suitability for international trade) delayed others' adoption of containerization. For example, looking at a later period, Kendall (1986) writes that "this revolution in transportation was almost indescribably expensive. 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." He also cites the results of a survey on the expenses involved in converting to containerization, published by the New York *Journal of Commerce* in June 20, 1977. While a conventional breakbulk ship cost \$7-8 per cubic foot to build, container ships cost \$25-30. In addition, there was the cost of buying steel containers, \$3,500 each, acquiring container-handling cranes, \$1,750,000 for 30-ton capacity, and securing waterfront space for terminals and marshaling yards, \$250,000-300,000 (Kendall, 1986, pp. 217-218).

The first country to follow America was Australia, in 1964. Australia had two important

[19] The Jones Act is another name for section 27 of the Merchant Marine Act of 1920.

[20] See Aghion and Howitt (1992), which formalizes Schumpeter's prediction of a negative relationship between competition and innovation (Schumpeter, 1943). If innovation is driven by the expectation of higher future profits, then lower competition (which raises profits) will increase the incentive to innovate. Aghion, Bloom, Blundell, Griffith, and Howitt (2005) reconcile the Schumpeterian theory with apparently contradictory empirical evidence by developing a new model that generates an inverted-U relationship between competition and innovation. They consider two opposing effects of competition on firms' innovation: the *Schumpeterian effect* (competition reduces post-innovation rents, therefore reducing innovation) and the *escape-competition effect* (competition reduces pre-innovation rents more than it reduces post-innovation rents, increasing the incremental profits from innovating). When competition is high, the *Schumpeterian effect* is more likely to dominate, while at low levels of competition the *escape-competition effect* will dominate. A lack of foreign competition, combined with competition between US companies operating US domestic maritime routes in the first half of the 20th century, generated an intermediate level of competition in the US domestic maritime industry during this period. At this intermediate level of competition, the *Schumpeterian effect* is still small while a strong *escape-competition effect* generates high incentives for innovation.

characteristics in common with the US: high labor costs and an internationally non-competitive shipping industry. Like the US, they adopted containerization for domestic trade only, with newly-built cellular container ships sailing between Melbourne, Fremantle, and Brisbane. And yet, "viewed at the start of 1965, the balance on containerization's first nine years was positive but unspectacular" (Levinson, 2008, p. 164).

Everything changed in 1966, with the start of transatlantic container services between the east coast of the US and Europe. Two other events significantly accelerated the pace of containerization in this second period. First, the international standard for containers was approved in 1967, after six years of discussions and negotiations.[21] Setting the standard meant that containers could become entirely intermodal. Unlike the first companies in the US and Australia, which had built incompatible container boxes (each adjusted to the characteristics of their specific domestic trading markets), the new companies of the late 1960s were following standard dimensions and specifications for the container box.[22]

Standardization was also an important driver of container leasing. The first container lines had their own container boxes which they made available to firms as needed. These boxes differed in size and structure,[23] and therefore when firms began to containerize they had to load their goods into ship-line-specific container boxes. This caused great inefficiency and high logistics costs. For example, if a firm had contracted its containerized shipping with Sealand (which used 35-foot containers) but imported intermediate inputs from firms that 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. He added, "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). Leasing companies, by providing an external source for container boxes, eased firms' adoption cost. As a result, they were key in reducing the fixed cost of containerization. They also played an important role in underwriting part of the risk of adoption, in meeting equipment shortfalls, and in mitigating trade imbalances (Ignarski, 2006, pp. 126-141). As we see in Figure 1, container leasing started in the 1960s, but it only became commonplace in the 1970s.

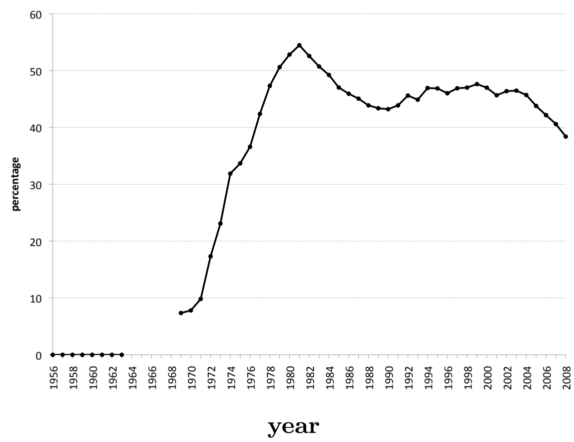
Another factor contributing to high fixed costs of using containerization was that container carriers only offered full container service, while many firms needed to carry smaller volumes. It was not until the 1980s that container carriers started to offer a limited number of less-than-container load (LCL) services, and even then, these services were not only infrequent but also extremely expensive. Small and medium-sized manufacturing firms wanting to use container-

[21] Negotiations at the International Standards Organization (ISO) had started in 1961, by American initiative and after an American standard had been approved in the same year. Not without much criticism from European and developing countries (UNCTAD's Group of 77), the ISO delegates approved the American design as the international standard.

[22] This was, however, not the case for existing companies. Both Sealand (previously Pan-Atlantic) and Matson clung to their traditional container dimensions for decades.

[23] They especially differed in the mechanism of their corner fittings, particularly relevant for handling by cranes and for stacking/storage.

Figure 1: Share of world's "box fleet" on operating lease



Notes: Fleet figures are rounded TEUs and include all types of container boxes. Sources: *Containerisation International*, Sep. 1983, and *Containerisation International Market Analysis, 2009*, "Container Leasing Market 2009."

ization had no choice but to maintain sophisticated distribution and inventory management systems in order to consolidate production to fill a container load.[24] The development of LCL services, especially in the late 1990s and 2000s, led to increased frequency of services and reduced LCL freight rates, while learning and competition between suppliers eventually reduced the price of external logistics services.[25] Both were key in allowing smaller orders to be cost effective, thereby lowering the overall fixed cost of using containerization.

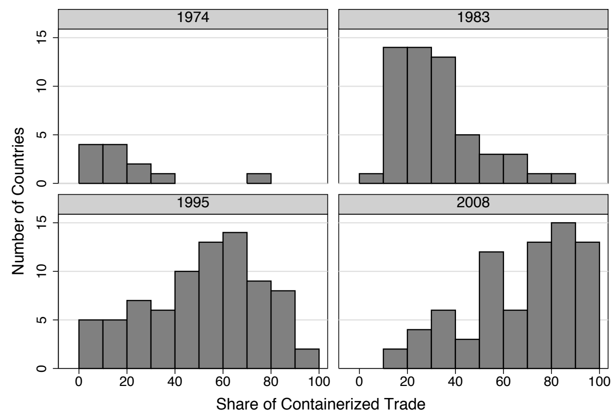
The second event that greatly hastened the march of containerization's diffusion was the growth in US military operations. Both the buildup of military forces in Vietnam after 1965 and the military escalation of the Cold War created large demand for container services. There was a third event in this period, the closure of the Suez Canal between 1967 and 1975, which had a mixed effect on the diffusion of containerization. On the one hand, longer and more expensive journeys between Asia and Europe erased part of the gains from using containerization. The containerships of the 1960s, which had been designed to pass through the Canal, were too slow for longer distances, but its closure required many containerships to make the long voyage around the Cape of Good Hope. This might explain, in part, the very slow growth of containerized trade in many countries during this period. We can see this in Figure 2, which shows the dispersion of container usage across countries and over time. By 1974, only the US had a share of containerized trade of near 70%; most countries were containerizing less than 20% of their trade. On the other hand, despite the slow growth in container usage, the closure of the Suez Canal created an incentive for adoption by countries which were now part of the main trade routes between Asia and Europe. Some southern African countries possibly joined the network

[24]See Kele (2011).

[25]The literature on technology diffusion has shown that learning and competition between suppliers are likely to lead to a drop in the price of a technology over time (Geroski, 2000, David & Olsen, 1992).

earlier than they would have otherwise.[26]

Figure 2: Dispersion of usage shares across countries and over time



While by 1974 containerization was mostly used in North America, Europe, and East Asia (see Figure 3 and Appendix E), by the end of third period containerization had reached almost all corners of the world. In 1983, 80% of countries had built at least one container port. However, despite worldwide adoption, use of the new technology was still slow, and only about 30% of world trade was containerized. Usage would only reach the 50% mark in the mid-1990s. During the last period, from 1984 to 2008, the network grew in density. Many countries greatly increased their number of container ports, and only thirteen small economies built their first container port. By 2008, only Gabon, Solomon Islands, and Somalia had yet to adopt containerization.

3 Theoretical Framework

In this section, I develop a theoretical framework that provides a rationale for the diffusion patterns that emerge from the data and motivates the econometric analysis presented in the empirical section. The theoretical framework is compatible with the two stylized facts discussed in the previous section: (1) the adoption of port infrastructure follows an S-shaped curve, and (2) the use of containerization in international trade moves much more slowly and linearly than the adoption of port infrastructure. The theoretical framework is also compatible with observed characteristics of the history of containerization (see below). It consists of three main features:

1. Monopolistic competition and heterogeneous firms (as in Melitz, 2003)

2. Two transportation technologies, containerization and traditional breakbulk shipping, which have different relative costs.

3. A transportation sector that constructs, maintains and operates the transport system

[26]For example, South Africa adopted containerization as early as 1971, one of the first 40 countries to join the network.

Figure 3: Diffusion of containerization across world ports

(a) Container ports in 1965

(b) Container ports in 1974

(c) Container ports in 1983

(d) Container ports in 2008

Notes: Maps created at GPSVizualizer.com using Google GPS coordinates. Sources: *International Shipping Statistics*, *Containerisation International Yearbook*, and *Lloyd's Ports of the World*, various issues.

Containerization involves lower transport costs than traditional breakbulk shipping but also requires more complex distribution logistics and inventory management systems that raise the fixed cost of servicing a foreign market. In each country, the transportation sector decides whether or not to build a container port, based on its expectations about domestic and foreign firms' usage of containerization. Depending on the existence of a container port, productivity differences between firms determine firms' decisions about which transportation technology to use. Of firms that export to countries with a container port, only the most productive find it profitable to use containerization.

Since it is costly to build and maintain a container port, the transportation sector charges a fee per unit of containerized trade that passes through the port[27] and will only build a container port when it expects to break even. Transportation sectors in different countries will break even at different points in time because of differences in country characteristics, differences in the characteristics of a country's trade partners, and differences in the decisions of a country's trade partners' transportation sectors. In addition, expansion of the network of trade partners with

[27]Port fees include, among other things, charges for "pilotage, tuggage, wharfage, dockage, line-handling, stevedoring, vessel overtime, rental of terminal cranes, and (moving) containers (. . .) to and off the vessel" (Talley, 2009, p. 112). I follow the port economics literature in representing port charges as a cost per unit of cargo passing through the port. For example, Talley (2009) considers a generalized port price per unit of throughput. While a unit of throughput can be measured either in tonnage or in twenty-foot equivalent units (TEUs), it is common among maritime data analyses and consulting publications to use average conversion factors between these two. (See, for example, Drewry Shipping Consultants Ltd, 2005 and The Tioga Group, Inc., 2009).

container ports and reductions in the fixed cost of containerization will raise the total amount of containerized trade and therefore the profits of the transportation sector.

3.1 Setup of the Model

I use the model of international trade in differentiated goods in which heterogeneous firms face fixed and variable costs of exporting as presented in Melitz (2003). I consider a world economy with M countries, indexed by $j = 1, 2, \ldots, M$. Each period, the preferences of a representative consumer in country j are given by a constant elasticity of substitution (C.E.S.) utility function over a continuum of varieties indexed by k,

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

where $\bar{x}_{j,t}(k)$ is consumption in country j of variety k at period t, and $\Omega_{j,t}$ is the mass of varieties available in country j at period t.

There are M varieties in the world, where each country has a measure one of firms, each producing a different variety. The varieties produced by country j's firms are different than those produced by country i's firms, for $i \neq j$. The elasticity of substitution between varieties, $\epsilon > 1$, is the same in every country.

Country j's consumers' utility maximization delivers the following demand for variety k at any given period t:

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

where $x_{j,t}(k)$ is country j's optimal consumption of variety k at period t, $Y_{j,t}$ is country j's income at period t (which equals expenditures), $\tilde{p}_{j,t}(k)$ is the delivered price of variety k in country j, and $P_{j,t}$ is the aggregate C.E.S. consumer price index at period t, given by

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

Firms in each country produce 1 unit of output with an optimal combination of inputs costing $c_{j,t}a$. The $c_{j,t}$'s are country-specific measures of the cost of a bundle of inputs, and they reflect differences in factor prices across countries. Parameter a is a firm-specific measure of the number of bundles of the country's inputs that need to be used to produce 1 unit of output. Its inverse is the firm's productivity. It is distributed according to the cumulative distribution function $G(a)$ with support $[0, a_H]$. This distribution function is the same in all countries and over time.

There are two additional costs if a firm from country j exports to country i: a fixed cost of exporting, $c_{j,t}f_{j,t}$, and an "iceberg transport cost," τ_{ij}. These are the same for all firms in the country. "Iceberg transport costs" mean that τ_{ij} units must be shipped from country j to country i for 1 unit to arrive. This is because $\tau_{ij} - 1$ units "melt away" during shipment. We can think of these lost units as ship lines' compensation for transporting the goods.[28] These fixed and variable trade costs are zero if the firm sells in the domestic market.[29]

In each period, exporting firms can choose between two transportation technologies: containerization and traditional breakbulk shipping. This choice 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 container-port infrastructure. When this infrastructure does not exist, firms can only use breakbulk shipping.[30]

The transportation sector is responsible for constructing port infrastructure, maintaining it, and operating the system of maritime transport. This sector may be public or private. There is no trade by land in the model, and all trade needs to pass through the port. There is also only direct shipping between countries.

Relative to breakbulk, a smaller amount of goods melts away during shipment with containerization. This amount is $\psi_{ij} - 1$ instead of $\tau_{ij} - 1$, with $1 < \psi_{ij} < \tau_{ij}$.[31] However, the transportation sectors in both country i and country j each take a fraction ϕ of the amount of containerized trade that passes through the container port as a fee for using it. Therefore, in order for 1 containerized unit to arrive at country i, firms in country j have to ship $\psi_{ij}/(1-\phi)^2$ units.[32] As a result, transport costs with containerization are[33]

$$t_{ij} = \frac{\psi_{ij}}{(1-\phi)^2} < \tau_{ij}, \qquad 0 < \phi < 1 \tag{4}$$

[28]If there are no changes in transportation technology, the τ_{ij}'s remain constant over time. They are related to constant geographical trade frictions, such as bilateral distance. On the other hand, even if there are no changes in transportation technology, the f_j's may change over time (see below). They are associated with distribution logistics and inventory management costs that are necessary to serve a foreign country.

[29]This is a convenient assumption as it ensures that firms will always sell in the domestic market (operating profits from selling in the domestic market are always positive), and it allows me to ignore domestic profits hereafter and focus only on profits obtained from sales in the foreign market.

[30]Since containerization relies on special infrastructure and equipment at the port, it is only when these are present that we can say a country has a container port rather than a traditional port. Broeze describes container ports as "highly specialized and purposeful creations" (Broeze, 2002, p. 172).

[31]Modeling the costs of containerized shipping as "iceberg transport costs" 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, there are several nuances in setting containerized freight rates that are not represented in the model. Container freight rates are generally calculated using three other pieces of information: (1) the container load ("full container load" vs. "less than full container load"), (2) the weight (adjusted by a commodity's stowage factor and special needs, for example, whether or not it needs to be refrigerated), and (3) the shipping route (major trading routes are allocated large container ships and therefore benefit from greater economies of scale; regional trade imbalances and the need to therefore ship empty containers in one direction also affect freight rates).

[32]The fee is exogenously determined (it may, for example, be determined by regulation) and is the same for all countries. Assuming that this exogenous fee is different between countries does not quantitatively change the results. However, it would be interesting to investigate what happens if this fee is endogenously determined. If transportation sectors charge an optimal fee, there may additionally be interesting results stemming from competition between transportation sectors.

[33]Why containerization allows for lower transport costs than traditional breakbulk shipping has been explained in Section 1. In brief, it is because containerization is an intermodal system that reduces ships' time in port, is more reliable, permits a considerable reduction in loss, pilferage, and damage, involves lower insurance fees, has large economies of scale, provides increased savings in labor costs, and involves fewer contracts.

Despite reducing transport costs, containerization raises the fixed cost of exporting. This is because firms need more sophisticated distribution logistics and inventory management systems and must buy or lease container boxes. Over time, the development of both container leasing and LCL services, as well as learning and competition between suppliers of logistics services, push this cost down, such that the fixed cost of containerization, $f^c_{j,t}$, decreases over time.[34] Since breakbulk has been around for millennia, I assume that the fixed cost of exporting using traditional shipping, $f^b_{j,t}$, has already reached its lowest bound and is therefore constant.[35] Hence, the relationship between the fixed costs of exporting using the two alternative transportation technologies is

$$f^c_{j,t} > f^b_j \qquad \text{where} \qquad f^c_{j,t+1} < f^c_{j,t} \qquad \forall t \tag{5}$$

3.2 Transportation Technology

These variable and fixed costs generate the following operating profits from exporting using breakbulk shipping and containerization respectively:

$$\pi^b_{ij,t}(a) = (1-\alpha)\left(\frac{c_{j,t}a}{\alpha P_{i,t}}\tau_{ij}\right)^{1-\epsilon} Y_{i,t} - c_{j,t}f^b_j \qquad \forall j \neq i \tag{6}$$

$$\pi^c_{ij,t}(a) = (1-\alpha)\left(\frac{c_{j,t}a}{\alpha P_{i,t}}t_{ij}\right)^{1-\epsilon} Y_{i,t} - c_{j,t}f^c_{j,t} \qquad \forall j \neq i \tag{7}$$

Define $(a^c_{ij,t})^{1-\epsilon}$ as the productivity cutoff at which these profits are the same, which equals

$$(a^c_{ij,t})^{1-\epsilon} = c^{\epsilon}_{j,t}\ \frac{f^c_{j,t} - f^b_j}{t^{1-\epsilon}_{ij} - \tau^{1-\epsilon}_{ij}}\frac{\alpha^{1-\epsilon}}{(1-\alpha)}\frac{P^{1-\epsilon}_{i,t}}{Y_{i,t}} \tag{8}$$

Define also $(a^b_{ij,t})^{1-\epsilon}$ as the productivity cutoff at which profits from exporting using breakbulk shipping are zero

$$(a^b_{ij,t})^{1-\epsilon} = c^{\epsilon}_{j,t}\ \frac{f^b_j}{\tau^{1-\epsilon}_{ij}}\frac{\alpha^{1-\epsilon}}{(1-\alpha)}\frac{P^{1-\epsilon}_{i,t}}{Y_{i,t}} \quad . \tag{9}$$

This component of the model is a variant of the framework in Helpman, Melitz, and Yeaple (2004), which extends Melitz (2003) by allowing firms to choose between exporting and establishing an affiliate in the foreign market. In line with Helpman et al. (2004)'s strategy, I assume that there are productivity levels at which exporters have positive profits from breakbulk that

[34] See discussion in Section 2.2.

[35] While improvements in forklift truck technology arguably reduced the fixed cost of traditional shipping, it is extremely unlikely that this reduction in the fixed cost was larger than containerization's. 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).

are higher than profits from containerization. This implies that

$$(a_{ij}^c)^{1-\epsilon} > (a_{ij}^b)^{1-\epsilon} \tag{10}$$

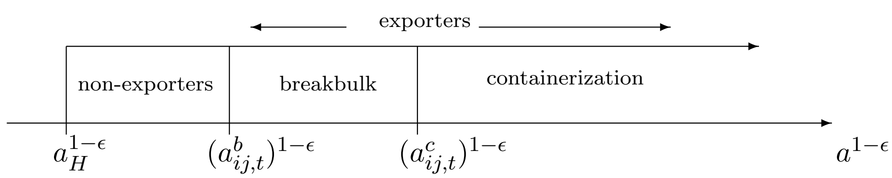
which is equivalent to assuming the following condition for variable and fixed costs of both transportation technologies:

$$t_{ij}^{\epsilon-1} f_{j,t}^c > \tau_{ij}^{\epsilon-1} f_j^b \quad \Leftrightarrow \quad \frac{f_{j,t}^c}{t_{ij}^{1-\epsilon}} > \frac{f_j^b}{\tau_{ij}^{1-\epsilon}} \tag{11}$$

The increase in fixed costs from using containerization is high relative to the reduction in variable trade costs. In equilibrium, firms use one of the transportation 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 $a_{ij,t}^c$. Firms with productivity levels between $(a_{ij,t}^b)^{1-\epsilon}$ and $(a_{ij,t}^c)^{1-\epsilon}$ use breakbulk transportation, while only the most productive exporters, with productivity above $(a_{ij,t}^c)^{1-\epsilon}$, find it profitable to use containerization. Figure 4 is a graphical representation of firms' decisions.[36]

Figure 4: Exporters' choice of transportation technology



To understand this result, consider the cost of exporting 1 unit using each technology. Unit transport costs (UTC) are a function of firms' productivity and can be expressed as

$$UTC^b(a) = c_{j,t} a \tau_{ij} + \frac{c_{j,t} f_j^b}{x_{ij}(a)} \tag{12}$$

$$= c_{j,t} a \left(\tau_{ij} + \frac{c_{j,t}^\epsilon \tau_{ij}^\epsilon f_j^b P_{i,t}^{1-\epsilon}}{\alpha^\epsilon Y_{i,t} a^{1-\epsilon}} \right) \tag{13}$$

and

$$UTC^c(a) = c_{j,t} a t_{ij} + \frac{c_{j,t} f_{j,t}^c}{x_{ij}(a)} \tag{14}$$

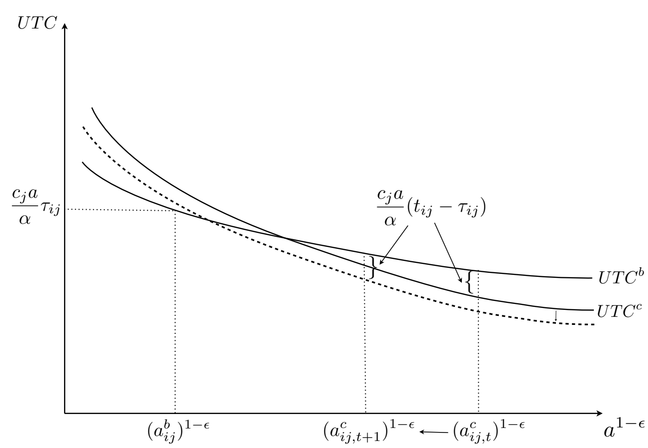
$$= c_{j,t} a \left(t_{ij} + \frac{c_{j,t}^\epsilon t_{ij}^\epsilon f_{j,t}^c P_{i,t}^{1-\epsilon}}{\alpha^\epsilon Y_{i,t} a^{1-\epsilon}} \right) \tag{15}$$

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

Condition (11) ensures that, compared to breakbulk, containerization requires high fixed costs relative to its savings in transport costs. This implies that only those firms which can spread the fixed transport cost over a larger amount of exports will be able to profit from exporting with containerization. For the same transportation technology, more productive firms export more (they charge lower prices), and the elasticity of substitution, which is higher than one ($\epsilon > 1$), magnifies this difference. Figure 5 shows how the unit transport costs of the two technologies vary with productivity. Containerization's unit transport costs are higher than breakbulk's for the least productive exporters, but they are lower for the most productive exporters. The point at which exporters switch from breakbulk to containerization is the productivity cutoff. At period t, exporters with productivity below $(a^c_{ij,t})^{1-\epsilon}$ choose breakbulk, while exporters with productivity above this cutoff choose containerization. Since firms set prices as a markup over marginal costs, the switch to containerization causes a reduction in the delivered price in the foreign market, and it is at the cutoff point that this reduction in average revenue is entirely compensated by the drop in unit costs.

Another way to understand firms' selection between the two technologies is by looking at their profits. Each period, the choice between transportation technologies does not affect firms' decisions to export but affects their export operating profits. For the reasons presented above, by choosing containerization, the most productive firms can enjoy higher profits than they would have using traditional breakbulk shipping, and the higher their productivity, the more their profits increase.

Figure 5: Selection of firms between transportation technologies



Because the fixed cost of using containerization is decreasing over time, the productivity cutoff is also decreasing over time.[37] Figure 5 illustrates this point for a one-period transi-

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

tion.[38] This implies that some of the less productive exporters, whose unit transport costs were previously too high, can now switch to containerization. The more time that passes since the introduction of containerization, the higher the number of exporters that optimally choose the new technology instead of traditional breakbulk shipping. In the limit, when the fixed cost of containerization is very low, all exporters will be using containerization. Moreover, if this fixed cost reaches a point where it is lower than the fixed cost of using traditional shipping, new exporters will be entering the world market.[39]

3.3 The Transportation Sector

In each country, the transportation sector faces a choice between keeping the traditional port infrastructure and building new port facilities adapted to containerization. The transportation sector needs to spend Γ_j units of the numeraire at period t for the container port to be ready in the next period, and it costs γ_j per unit of containerized trade to maintain and operate it.[40] Adoption of containerization is an absorbing state; that is, after the container port is constructed, it operates forever. Investment in containerization is irreversible.[41]

When firms use container services and equipment at country j's container port (namely, those firms of country j which containerize exports and those foreign firms which containerize imports to country j), the transportation sector charges them a fee, ϕ, per unit of containerized trade.[42] The fee for breakbulk services is normalized to zero.

Under perfect foresight, the present value of the profits of country j's transportation sector from building the container port at period t are

$$\Pi_{j,t} = \sum_{s=t}^{\infty} \rho^{(s-t+1)} \left(\phi - \gamma_j\right) T^c_{j,s} - \Gamma_j \tag{16}$$

where $T^c_{j,s}$ is country j's aggregate containerized trade at period s, $s \geq t$, and ρ is the discount factor. For simplicity, I assume zero profits from operating a traditional port.

Define A_k as an indicator variable which equals 1 when there is a container port in country k and zero when country k has only a traditional port. In each period, country j's total containerized trade with k depends on the existence of a container port in k (A_k) and, conditional on k having a container port, on domestic and foreign firms' decisions about which transportation technology to use. Therefore, j's aggregate containerized trade at period s can be expressed as

$$T^c_{j,s} = \sum_{k \neq j} T^c_{kj,s} = \sum_{k \neq j} A_{k,s} \left(m^c_{kj,s} + m^c_{jk,s}\right) \tag{17}$$

[38] For simplicity, I assume that c_j does not change between t and $t+1$.

[39] While I cannot confirm this result with my dataset, understanding if containerization fostered the entrance of new exporters is an interesting direction for future research.

[40] For simplicity, I assume that these costs are constant over time, but I will relax this assumption in the empirical analysis.

[41] 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.

[42] As explained in the previous section, this fee raises containerization's transport costs.

where

$$m^c_{kj,s} = \left(\frac{c_{j,s}t_{kj}}{\alpha}\right)^{1-\epsilon} P^{\epsilon-1}_{k,s} Y_{k,s} \int_0^{a^c_{kj,s}} a^{1-\epsilon}\, dG(a) \tag{18}$$

$$m^c_{jk,s} = \left(\frac{c_{k,s}t_{jk}}{\alpha}\right)^{1-\epsilon} P^{\epsilon-1}_{j,s} Y_{j,s} \int_0^{a^c_{jk,s}} a^{1-\epsilon}\, dG(a) \tag{19}$$

Country j's transportation sector builds a container port at period t if domestic and foreign firms containerize enough trade over time that it will make positive profits, that is, $\Pi_{j,t} > 0$.

3.4 Equilibrium

The structure of the transportation sector's problem implies the existence of network effects: an increase in the number of countries in the container network will (non-strictly) increase the profits of all transportation sectors.[43] An additional implication is that each transportation sector makes zero profits when all other transportation sectors remain with traditional ports (if no one adopts, there is no one to trade with using containerization).

Given perfect and complete information, there is no value to waiting. Therefore, if it were the case that when adoption is profitable for one transportation sector, it is also profitable for all others, this problem would have two Nash equilibria: either all transportation sectors adopt containerization immediately, or no one ever does.

However, I introduce two additional assumptions, in line with the history of containerization, to match what we observe in the data. First, I assume that there is at least one country in the world whose transportation sector makes positive profits with a container port even if there are no other countries with container ports. This country is the US.[44] It was the first country to adopt containerization and used it for domestic trade only from 1956 to 1965.[45] This assumption guarantees that there is at least one country which adopts containerization immediately.

Second, I consider a limit to network effects such that other transportation sectors adopt containerization sequentially. I assume that transportation sectors initially make negative profits from containerization, even if all other countries have already built a container port. This assumption can be justified by going back to equation (16). Transportation sector j will make negative profits from constructing a container port if Γ_j is very high, or if no firm in country j finds it profitable to use containerization even if it is available. The latter occurs when containerization's productivity cutoff is too high: $(a^c_{ij})^{1-\epsilon} \geq a_L^{1-\epsilon}$ for all countries i that are j's trade partners. This is conceivable if firms' fixed cost of exporting using containerization, f^c_j, is still very high or if the gain from decreased transportation costs, $\tau_{ij} - t_{ij}$, is too small.

Transportation sectors' profits need not remain negative forever since firms' fixed cost of exporting using containerization declines over time, due to learning and competition between suppliers and the spread of leasing companies (see Section 2.2). Furthermore, this drop in $f^c_{j,t}$

[43] The reason why profits are not strictly increasing in the number of countries in the container network is that, since productivity is bounded, there might be a subset of countries with zero bilateral trade. For those pairs, the adoption decision of one transportation sector does not directly affect the other's.

[44] The reasons for US' initial adoption have been discussed in detail in Section 1.

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

will affect firms' productivity cutoffs differently according to country.[46] Consequently, there is a threshold period t'_j when each transportation sector breaks even and adopts containerization. This threshold depends, for example, on how much the country trades with previous adopters, the magnitude of the gain from decreased transportation costs, differences in factor prices, and differences in the cost of building the container port. However, this threshold is not unique; it depends on other countries' decisions. This interconnection between countries' adoption decisions generates multiple equilibria but all of the same nature. They correspond to sequences of adoptions where at least one country adopts immediately and all other countries adopt when firms' fixed costs of using containerization are low enough that the transportation sector breaks even. Because of the limit to network effects imposed by fixed costs, at each period t there is a range of potential adoptions, each producing a different S-shaped path. Diffusion is faster or slower depending on which equilibrium prevails. Moreover, network effects explain why the resulting curve is S-shaped. The more countries that have adopted containerization, the stronger the effect of decreasing fixed costs on transportation sectors' profits. Analytically, this corresponds to having more countries included in the summation presented in equation (17).

To understand these multiple equilibria, we can look at a 2-country case. Assume that, at a given period t, both Portugal and England's transportation sectors do not break even from adopting containerization separately, but given the large amount of bilateral trade between the two countries, they would break even if they both adopted at t. There are therefore two Nash equilibria, one where neither country adopts and another where both adopt at t. Diffusion is slower in the former and faster in the latter, and decreasing fixed costs ensure that, if Portugal and England did not adopt at t, they will do so in the future. With M countries, multiple equilibria will originate from several combinations of the situation described above.

One way we can rule out these multiple equilibria is by assuming communication between countries. If, at each period t, countries can credibly negotiate with each other and governments can guarantee their adoption, the maximum number of countries that can adopt will do so. In this case, there will be only one S-shaped path of adoptions, the fastest.

The model also explains why containerized trade moves more slowly and linearly than adoption of port infrastructure. First, since the decision to build a container port is based on the present value of future containerized trade, container-port infrastructure will be constructed ahead of firms' usage of the technology. Second, weaker network effects at the firm level (given heterogeneity) generate a more linear expansion of containerized trade. These predictions are in line with what we observe in Figure 1.

While the model provides simple predictions for the adoption and usage of containerization, it 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 transport costs of all firms in a given country equally, but only the most productive choose to use it. In reality, of course, 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.,

[46] The reduction in containerization's productivity cutoff caused by the drop in $f^c_{j,t}$ depends on $c_{j,t}$, $Y_{j,t}$, $P_{j,t}$, $\tau_{ij,t}$, and $t_{ij,t}$ (see equation 8).

meats), and dangerous products take longer to pass security checks and clear through 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 capture the role of containerization in generating today's global supply chains, which are an important feature of the global economy.

Finally, in considering only direct shipping routes between countries, the model abstracts from the rise of some container ports as international hubs (e.g., Singapore).

Despite these shortcomings, the theoretical framework presented above still captures most of the main features of the diffusion of containerization, both in terms of adoption of container-port infrastructure and firms' usage of this technology.

3.5 Empirical Implications

In this section, I study how different variables affect transportation sectors' profits and, consequently, the timing of adoption, and derive the empirical specification implemented in Section 4. While equations (16) to (19) give exact measures of transportation sector's profits, in reality, decision-makers do not perfectly observe future values of all the variables included in these equations. Some of these variables are often stochastic and uncertain, such as income and input costs. However, the rational decision-maker decides when to build a container port on the basis of all information available to her at each time t. This includes her knowledge of the structure of the market, firms' decision rules, and the probability distribution of stochastic processes. Therefore, at period t, j's transportation sector's expectation for aggregate containerized trade at period s, $\tilde{T}^c_{j,s}$, corresponds to the conditional expectation of $T^c_{j,s}$, given the information set Ω_{t-1}.

$$\tilde{T}^c_{j,s} = E[T^c_{j,s}|\Omega_{t-1}] \equiv E_{t-1}T^c_{j,s} \tag{20}$$

Without specifying the processes driving stochastic variables such as income and input costs over time, I assume that these are known to the transportation sector and that the conditional expectation of $T^c_{j,t}$ can be summarized in a coefficient θ such that $E_{t-1}T^c_{j,t} = \theta T^c_{j,t-1}$ and $E_{t-1}T^c_{j,s} = \theta^{s-t+1}\, T^c_{j,t-1}$. Given these assumptions, j's transportation sector's expected profits can be expressed as

$$\tilde{\Pi}_{j,t} = (\phi - \gamma_j) \sum_{s=t}^{\infty} \sum_{k \neq j} (\rho\theta)^{s-t+1}\, T^c_{kj,t-1} - \Gamma_j \tag{21}$$

Assuming $\rho\theta < 1$, we can rewrite equation (21) as $\tilde{\Pi}_{j,t} = (\phi - \gamma_j)/(1-\rho\theta)\; T^c_{j,t-1} - \Gamma_j$ and the adoption condition becomes $(\phi - \gamma_j)/(1-\rho\theta)\; T^c_{j,t-1} > \Gamma_j$. Taking logs on both sides, we get that adoption implies

$$a_1 + \ln(\phi - \gamma_j) + \ln(\hat{T}^c_{j,t-1}) - \ln(\Gamma_j) > 0 \tag{22}$$

where $a_1 = -\ln(1-\rho\theta)$ is a constant term.

Containerized trade, $T^c_{j,t-1}$, cannot be observed before adoption occurred. In other words, before there is a container port, there can be no containerized trade. However, despite not being able to observe it, j's transportation sector can still estimate the amount of containerized trade that would eventuate if there were already a container port in j, which will be consistent with the structure of the model, namely equations (17) to (19). I denote this potential containerized trade by $\hat{T}^c_{j,t-1}$ and explain its estimation below.

Equation (22) explains why countries decide to build container ports at different points in time. All else equal, transportation sectors in countries where it is more costly to construct a container port (Γ is high), or where it is more costly to maintain and operate it (γ is high), have lower profits and are therefore less likely to adopt containerization early. Trade also matters: countries where more firms would decide to containerize exports have higher profits and are therefore more likely to adopt containerization early.

To estimate equation (22), I define the latent variable $z_{j,t}$ as

$$z_{j,t} = a_1 + \ln(\phi - \gamma_j) + \ln(\hat{T}^c_{j,t-1}) - \ln(\Gamma_j) \tag{23}$$

I represent the uncertainty associated with unmeasured fixed and variable trade frictions and country characteristics by an $i.i.d.$ stochastic term, μ^z, and as a result, the adoption condition can be expressed as $z_{j,t} + \mu^z_{j,t} > 0$. Assuming that μ^z is distributed independently of $z_{j,t}$ with a symmetric cumulative distribution $H(\mu^z)$, we can express the hazard rate of adoption at period t as

$$\begin{aligned} \mathcal{H}_j(t) &= \Pr(A_{j,t} = 1 | A_{j,t-1} = 0, \text{observed variables}) && (24)\\ &= \Pr(z_{j,t} + \mu^z_{j,t} > 0|.) && (25)\\ &= \frac{H(-z_{j,t}) - H(-z_{j,t-1})}{1 - H(-z_{j,t-1})} && (26)\\ &\equiv \mathcal{H}\left(\eta_j, \zeta_j, \hat{\nu}^c_{j,t-1}\right) && (27) \end{aligned}$$

where $\eta_j = \ln(\Gamma_j)$ are costs associated with adoption (i.e, with constructing the container port), $\zeta_j = \ln(\phi - \gamma_j)$ are variable port costs, and $\hat{\nu}^c_{j,t-1} = \ln(\hat{T}^c_{j,t-1})$ is log containerized trade.

As explained above, because $\hat{\nu}^c_{j,t-1}$ cannot be observed before adoption, it needs to be estimated. This can be obtained by using equations (17) to (19). To produce a clear link between the model and the empirical analysis, I focus on the case of symmetry across countries and assume that each country is a fraction b of world income ($Y_{i,t} = bY^w_t, \ \forall j$). These assumption will be relaxed in the empirical analysis. In addition, I assume that input costs are the same in every country and normalized to one, and as is standard in the literature, that firms' productivity follows a Pareto distribution with shape parameter $\kappa > \epsilon - 1$,[47] such that $G(a) = (a/a_H)^\kappa$ and

$$\int_0^a a^{1-\epsilon} dG(a) = \frac{\kappa}{\kappa - \epsilon + 1} \frac{a^{\kappa-\epsilon+1}}{a^\kappa_H} \tag{28}$$

[47] See, for example, Helpman et al. (2004) and Helpman, Melitz, and Rubinstein (2008).

Under these assumptions, containerized trade can be expressed as

$$T^c_{j,t} = a_2 \left(\frac{Y^w_t}{P^{\epsilon-1}_t}\right)^{\frac{\kappa}{\epsilon-1}} \left(f^c_{j,t} - f^b_j\right)^{\frac{\kappa-\epsilon+1}{1-\epsilon}} \sum_{k\neq j} A_{k,t}\ t^{1-\epsilon}_{kj} \left(\frac{t^{1-\epsilon}_{kj} - \tau^{1-\epsilon}_{kj}}{1+\frac{f^c_{k,t}-f^b_k}{f^c_{j,t}-f^b_j}}\right)^{\frac{\kappa-\epsilon+1}{\epsilon-1}} \tag{29}$$

and $\nu^c_{j,t-1}$ can therefore be estimated using equation (29).

In the next section, I operationalize this two-step approach suggested by the model in order to understand the determinants of adoption and usage of containerization.

4 Empirical Analysis

The two-step approach suggested by the model implies first estimating equation (29) and then using that estimate of containerized trade in equation (27). However, while the theoretical framework presented in the previous section is built on the assumption that all firms produce general cargo goods, the empirical analysis requires that I relax that assumption to allow for differences in the composition of trade. A simple way to control for these differences is to normalize $T^c_{j,t}$ by general cargo trade, $T^G_{j,t}$, and to add the shares of general cargo trade, $S^G_{j,t} = T^G_{j,t}/T^T_{j,t}$, and total trade, $T^T_{j,t}$, as controls in the adoption estimation (see equation 33 below). The empirical analysis also requires that I relax the symmetry assumption used in the model. Without symmetry, j's income and j's trade partners' income will enter the equations for containerized and total trade both directly and as part of the network term. As a result, conditional on adoption, the share of containerized trade (out of total general cargo trade), $S^c_{j,t}$, can be expressed as a function of four terms:

$$S^c_{j,t} = f\left(\frac{f^c_{j,t} - f^b_j}{f^b_j}, \sum_{k\neq j} A_{k,t}, \sum_{k\neq j} A_{k,t}\ g_1(Y_{k,t}), \sum_{k\neq j} A_{k,t}\ g_2(\tau_{kj}, t_{kj})\right) \tag{30}$$

The first term is the fixed cost of containerization relative to the cost of breakbulk, the second is the number of j's trade partners with container ports, the third is a measure of income in j's container network, and the fourth and last term is a function of j's average transport costs to trade partner countries with container ports, using both technologies.

Assuming that $f(.)$ can be log-linearized, the resulting two-step econometric model is:

$$\text{Step 1:} \qquad s^c_{j,t} = \beta_0 + \beta_1 \ln\left(\frac{f^c_{j,t} - f^b_j}{f^b_j}\right) + \beta_2 \ln \sum_{k\neq j} A_{k,t}\ g_1(\tau_{kj}, t_{kj}) \tag{31}$$

$$+\beta_3 \ln \sum_{k\neq j} A_{k,t} + \beta_4 \ln \sum_{k\neq j} A_{k,t}\ g_2(Y_{k,t}) + \mu^s_{j,t}$$

$$\text{Step 2:} \qquad log\left(\frac{\lambda(t|\mathbf{X}_{t-1})}{1-\lambda(t|\mathbf{X}_{t-1})}\right) = \delta\mathbf{X}_{t-1} + \mu^h_{j,t} \tag{32}$$

Step 1 estimates a linear model in which the dependent variable is log share of containerized trade (out of general cargo trade), $s^c_{j,t} = \ln(S^c_{j,t}) = \ln(T^c_{j,t}/T^G_{j,t})$. Step 2 estimates a discrete-time hazard model. I specify the hazard function $\mathcal{H}(.)$ as logistic, based on Figure 1(a) and the results of the model, and also because the logistic is the most commonly used discrete-time hazard function in the literature. The dependent variable in equation (32) is the conditional log odds that adoption occurs at year t (given that it did not occur before), and it is a linear function of $\mathbf{X}_{t-1}$. The product $\delta\mathbf{X}_{t-1}$ is expressed as

$$\delta\mathbf{X}_{t-1} = \delta_1\eta_j + \delta_2\zeta_j + \delta_3\hat{s}^c_{j,t-1} + \delta_4 s^G_{j,t-1} + \delta_5 T_{j,t-1} \tag{33}$$

where η_j are adoption costs, ζ_j are variable port costs, $\hat{s}^c_{j,t}$ is the predicted log share of containerized trade (estimated in step 1), $s^G_{j,t}$ is the log share of general cargo trade, and $T_{j,t}$ is log total trade.

4.1 Data

In this section, I explain and describe the data which I use to estimate the previous two-step model.[48] I start with the explanatory variables in step 1, followed by those in step 2. The first variable, $(f^c_{j,t-1} - f^b_j)/f^b_j$, is the fixed cost of exporting using containerization relative to the cost of breakbulk. This cost is tied to various country-specific factors such as the quality of physical infrastructure and administrative hurdles associated with exporting (for example, customs, tax, and security procedures). These factors are common to either mode of exportation and, to the extent that they tend to remain relatively constant over time, will be absorbed by country fixed effects. Country fixed effects will also absorb other unobserved factors that have affected the cost of breakbulk shipping for millennia and remain relatively constant today. However, the fixed cost of using containerization involves additional costs, which accrue from more complex logistics and distribution management services and the acquisition or leasing of container boxes. We can observe the evolution of these additional costs in two ways: first, through the spread of container-leasing companies, and second, through the stock of land transportation infrastructure.

Standardization in 1967 and the resultant advent of container-leasing changed early logistics systems. Firms became able to contract with different freight forwarders without having to be wedded to a single ship line, and this reduced their costs in terms of logistics and time. I use data on the share of the world's "box fleet" on operating lease as a way to capture the effect of container leasing on firms' fixed costs. However, since these data only vary by year and not by country, I cannot measure cross-country differences in containerization's fixed costs. To do that, I also consider another aspect of containerization, intermodality.

The potential of containerization can only be fully exploited if there is adequate intermodality. Standardization played an important role here, as well, since it made it possible for land and sea carriers to handle one another's containers. By doing so, it allowed firms (or freight forwarders that they had contracted) to select the most appropriate route for their shipments, whether it was the fastest route or the least costly. The more routes a firm can choose from, the larger an advantage standardization affords. I measure the intermodal potential of a country by the density of its network of railways and paved roads (the length of railway lines and paved roads relative to the area).

[48] See Appendix F for variable definitions and data sources.

The second variable, $\sum_{k \neq j} A_{k,t} \; g_1(\tau_{kj}, t_{kj})$, is a function of transportation costs between a country and its container network. In the absence of internationally comparable freight cost data that go as far back as the 1950s, I look at the most cited determinant of transportation costs, geographical distance. In particular, I use maritime distance between countries.[49] I assume that containerization had a different impact on countries' transportation costs depending on their geographical remoteness. The reasons for this are twofold. First, there is narrative evidence showing that containerization reduced transit times relatively more for longer journeys. This is because, previously, ships making longer trips often called at various ports during the journey, and with breakbulk, they could stay docked at each of these ports for weeks.[50] Containerization not only reduced transit time and the number of stops, but more importantly, it reduced the time spent at each intermediate port. The second reason for the different impact of containerization according to distance is related to economies of scale. Longer routes are served by huge container ships, some of which can now hold up to 18,000 TEUs.[51] Moreover, as Levinson points out, "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."[52]

If containerization did, in fact, provide a substantial reduction in transportation costs of firms located in countries that are geographically further away from the container network, I should find a positive effect of "distance to network" on the share of containerized trade. A country's distance to the network is the weighted average maritime distance to all its trade partners that have adopted containerization, weighted by the trade share of each trade partner.[53]

The other two elements of equation (31) depend on the number of countries in the container network and the network's income. Table 2 presents these and other measures of network effects, which I include in the estimation. I also include two additional explanatory variables, trade openness and population, to control for countries' exposure to foreign trade and their population size.

In addition to the estimated share of containerized trade, the hazard model in step 2 includes cost measures associated with building, maintaining, and operating the container port, the share of general cargo trade, and the size of the country in trade terms (see equation 33). I use real GDP per capita as a proxy for the costs associated with building, maintaining, and operating the container port, in particular labor costs. According to the Balassa-Samuelson effect (Balassa, 1964, Samuelson, 1964), real income differentials explain wage and price level differentials between economies. This is because productivity in the tradable sector tends to be higher in richer than in poorer countries, whereas productivity in the nontradable sector tends to be the same across all countries. If purchasing power parity (PPP) holds for tradable goods and there

[49] I use the "Reeds Maritime Distance Tables" (Reynolds & Caney, 2010), which are the standard reference in the shipping business.

[50] For example, a 1972 study by McKinsey & Company observed the following: "Previously, Australia-bound ships had spent weeks calling at any of eleven European ports before starting the southbound voyage. Containerships collected cargo only at huge container ports at Tilbury, Hamburg, and Rotterdam, whose enormous size kept the cost of handling each container low. Previously, shipments took a minimum of 70 days to get from Hamburg to Sydney, with each additional port of call adding to the time; containerships offered transit time of 34 days, eliminating at least 36 days' worth of carrying costs" (Levinson, 2008, p. 220).

[51] White (2011).

[52] Levinson, 2008, pp. 268–269.

[53] In order to exclude cyclical variations, I calculate trade shares using averages over the previous 5 years.

Table 2: Network measures

Variable	Definition
Network nr. countries	$\sum_{k\neq j} \omega_{kj,t}\ A_{k,t}$
Network usage	$\sum_{k\neq j} \omega_{kj,t}\ S_{k,t}$
Network ports	$\sum_{k\neq j} \omega_{kj,t}\ cports_{k,t}$
Network real GDPpc	$\sum_{k\neq j} \omega_{kj,t}\ GDP_{k,t}\ A_{k,t}$
Network nr. neighbors	$\sum_{k\neq j} \omega_{kj,t}\ A_{k,t}\ border_{kj}$
Neighbors usage	$\sum_{k\neq j} \omega_{kj,t}\ S_{k,t}\ border_{kj}$
Neighbors ports	$\sum_{k\neq j} \omega_{kj,t}\ cports_{k,t}\ border_{kj}$
where	
$\omega_{kj,t}$	k's share in country j's total trade (average over the period from $t-4$ to t.
$A_{k,t}$	Dummy variable that takes the value 1 if country k has adopted containerization by year t
$S_{k,t}$	k's share of containerized trade in year t
$cports_{k,t}$	Number of container ports in country k at year t
$GDP_{k,t}$	k's real GDP per capita
$border_{kj}$	Dummy variable that takes the value 1 if countries j and k share a border

is free factor mobility, high wage levels in the tradable sector push up wages in the nontradable sector, leading to higher wages overall in richer countries. In addition, high wages and strong unions tend to be associated. Powerful longshoremen unions have been connected with numerous delays in ports' adoption of containerization, and there are various historical accounts of protracted negotiations between unions, port authorities, and governments.[54] Prolonged strikes have also caused exceptionally lengthy delays at ports, with container ships remaining docked for the duration.[55]

In addition, I use institutional barriers as a proxy for the adoption cost. They affect the political cost of building any new infrastructure, in particular a container port. The political

[54] See Levinson (2008), pp. 120–122, for an example of negotiations involving the International Longshoremen's Association (ILA), the New York Shipping Association, and three mediators nominated by President Kennedy.

[55] For example, see Levinson (2008), pp. 203–206, for a description of Tilbury's prolonged closures in the late 1960s, and how Felixstowe, a small ferry port with "no militant unions," profited from London's container service disruptions.

economy literature has identified several institutional barriers that impair decision processes, especially when there are large amounts of money involved. These include the effectiveness of the judicial system, rule of law, and the general openness of political institutions. I use the measures of "efficiency of the judiciary" and "rule of law" from La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998). They are time-invariant and are scaled from 1 to 10, with lower scores corresponding to lower levels of judicial efficiency and rule of law. Constraints on the chief executive, from Polity IV, measure the general openness of political institutions. They are scaled from 1 to 7 and vary over time. These institutional barriers are also a proxy for financial development, which is another important determinant of the initial cost of building a container port. The law and finance literature has shown that in countries where legal systems enforce property rights and protect investors' legal rights, savers are more willing to finance firms, and financial markets are more developed. In contrast, legal institutions that fail to support property rights or protect private contracts hinder corporate finance and inhibit financial development (La Porta et al. 1998, 2000, Chinn and Ito 2006).

In the absence of a better and more direct measure, I use oil exports to measure non-containerizable trade. Specifically, I use a dummy variable that takes the value one if a country's oil exports are larger than two thirds of its merchandise exports.

Finally, I measure a country's trade size by its share in world trade. I include additional controls such as country area, trade with early adopters (the United States, Australia, Belgium, the Netherlands, and the United Kingdom), an island dummy, and the length of coastline. Table 3 presents descriptive statistics.

4.2 Results

4.2.1 Containerized Trade

Tables 4 to 6 present the results from estimating equation (31), using ordinary least square with fixed effects. Since I estimate the share of containerized trade conditional upon the decision to adopt, I use only observations with positive values for containerized trade. Standard errors are clustered by country, which corrects for residual dependence between observations of the same country in different years.

Table 4 shows that fixed costs have a positive effect on usage of containerization. As discussed before, fixed costs of using containerization are negatively associated with increases in the share of leased boxes and the stock of domestic land transportation infrastructure. The positive and significant coefficients of these variables, therefore, indicate that reductions in the fixed cost increase containerized trade. Even though the density of railway lines is not statistically significant in specifications 1 and 2, it has positive and significant coefficients in specifications 3 and 4, which do not include the density of paved roads as an explanatory variable. This is because the length of paved roads and railway lines are positively correlated (the correlation coefficient is 0.31), resulting in insignificant coefficients for the weaker variable, due to measurement error. Nonetheless, the densities of paved roads and railway lines are jointly significant at the 1% level (see p-values in the last row of Table 4).[56]

Distance to the network measures how far a country is from the container network, weighted

[56] I also present p-values for this joint significance test in subsequent estimations (see Tables 5 to 9).

Table 3: Descriptive statistics

	N	Mean	St.dev	Min	Max	Median
Share containerized trade	3934	0.255	0.304	0	1	0.092
World share leased boxes	7153	31.307	19.966	0	54.460	43.370
Density of paved roads	4400	0.376	0.797	0	6.328	0.046
Density of railway lines	5082	0.083	0.911	0	12.951	0.005
Distance to network, log	4546	7.734	1.234	0.012	9.195	8.177
Trade openness, log	5772	-2.021	0.822	-9.621	2.773	-2.006
Population, log	6558	15.577	2.032	10.523	20.999	15.799
Network nr. countries	6575	0.772	0.301	0	1	0.919
Network usage	5932	0.313	0.212	0	0.860	0.336
Network ports	6492	12.336	7.825	0.014	44.571	12.345
Network real GDPpc, log	6492	9.450	0.925	3.584	10.552	9.738
Network nr. neighbors	7151	1.256	1.552	0	9	1
Neighbors usage	2724	0.303	0.227	0	0.983	0.255
Neighbors ports	3686	9.654	10.052	1	56	6
Ports/coastline	6888	0.002	0.006	0	0.083	0.001
Banking crisis, 5 yrs	7153	0.089	0.284	0	1	0
Real GDPpc PPP, log	5830	8.508	1.243	4.767	11.917	8.570
Share world trade	6577	1.555	3.795	0	33.434	0.261
Area km2, log	7153	11.495	2.636	1.946	16.654	12.005
Oil exporter	7153	0.096	0.295	0	1	0
Executive constraints	5498	4.262	2.341	1	7	4
Rule of law	2440	6.850	2.625	1.9	10	6.780
Efficiency of judiciary	2440	7.640	2.062	2.5	10	7.250
Trade with USA, real bn.$	6547	2.242	8.538	0	135.550	0.229
Trade with AUS, real bn.$	6229	0.211	0.789	0	14.272	0.011
Trade with BEL, real bn.$	5006	0.402	1.745	0	21.536	0.024
Trade with NLD, real bn.$	6611	0.601	2.464	0	52.379	0.045
Trade with GBR, real bn.$	6670	0.836	2.545	0	34.558	0.104
Island	7047	0.306	0.461	0	1	0
Coastline, log	6888	6.997	1.675	2.485	12.216	7.041

by the relative importance of each trade partner. If distance is a good measure of transportation costs and containerization's impact on transportation costs increases with distance, firms in countries that are relatively farther away from the container network should have larger transportation cost gains from using containerization.[57] However, distance to the network is not significant in any specification, indicating that the effect of containerization on transportation costs works through a different channel. Alternatively, since most of the variation in the distance to network measure is cross-sectional (any time variation in a country's distance to the network comes only from changes in its trade partners' trade shares, which are slow moving), its effect is possibly absorbed by country fixed effects, which are included in all specifications.[58]

[57] See discussion in the previous section.

[58] Specifications 2, 4, and 6 include, additionally, year fixed effects.

Table 4: Fixed costs: leasing and domestic transportation network (ordinary least squares)

	(1)	(2)	(3)	(4)	(5)	(6)
Years since adoption	0.128**	0.026	0.142**	0.062**	0.128**	0.046+
	(0.020)	(0.025)	(0.018)	(0.016)	(0.018)	(0.024)
Years since adoption, sq	-0.002**	-0.002**	-0.002**	-0.002**	-0.002**	-0.002**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
World share leased boxes, t-1	0.008	0.048*	0.013*	0.039*	0.008	0.043*
	(0.006)	(0.021)	(0.006)	(0.019)	(0.006)	(0.021)
Density of paved roads, t-1	0.217*	0.215*			0.202*	0.206*
	(0.097)	(0.101)			(0.094)	(0.093)
Density of railway lines, t-1	5.591	5.794	8.062+	8.867*		
	(4.016)	(4.016)	(4.236)	(4.251)		
Distance to network, log t-1	-0.243	-0.250	-0.241	-0.232	-0.233	-0.245
	(0.234)	(0.246)	(0.233)	(0.245)	(0.231)	(0.246)
Trade openness, log t-1	0.249	0.291	0.283+	0.300+	0.298+	0.337+
	(0.156)	(0.200)	(0.142)	(0.179)	(0.157)	(0.194)
Population, log t-1	0.253	0.272	-0.117	-0.098	0.278	0.272
	(0.322)	(0.346)	(0.316)	(0.333)	(0.307)	(0.331)
Network nr. countries, t-1	2.310**	1.813*	2.138*	1.808*	2.113*	1.646+
	(0.820)	(0.867)	(0.812)	(0.906)	(0.811)	(0.869)
Constant	-5.924	-9.317	0.788	-2.519	-10.000*	-8.439
	(4.833)	(5.694)	(7.025)	(4.961)	(4.601)	(5.436)
Observations	1504	1504	1610	1610	1698	1698
R^2	0.79	0.80	0.79	0.80	0.79	0.80
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	No	Yes	No	Yes	No	Yes
F-test (p-value)	0.007	0.006				

Notes: The dependent variable is the share of containerized trade in logs. The last line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Other explanatory variables in Table 4 are the number of years since adoption and its squared value, trade openness, population size, and the weighted-average number of countries in the container network (a measure of network effects). The coefficients of the number of years since adoption and its squared value indicate a concave relationship between time and containerized trade: containerized trade grows initially and starts to move more slowly after several years have passed since adoption. Higher levels of trade openness, as well as a larger size of its container network, increase a country's usage of containerization, but its population size has no effect on usage of the technology. The effect of network size is fairly large: a two-standard-deviation increase in the average number of trade partners using containerization, 0.6, increases a country's usage between 1% and 1.4%. The next table explores network effects in more detail.

Table 5 estimates the influence of several measures of network effects on containerized trade. Column 1 replicates specification 2 in Table 4, estimating the effect of network size only, and columns 2 to 5 include additional measures of network effects. Network size, network usage, and network income have positive and significant effects on a country's usage of containerization. Specifications 2 to 5 show that, once I control for other network characteristics, the effect of network size becomes slightly smaller. A two-standard-deviation increase in network size increases the share of containerized trade between 0.26% and 1.1%. A similar increase in the average usage level in the network, 0.42 percentage points, increases the share of containerized trade between 0.53% and 0.64%. Similarly, a two-standard-deviation increase in network's average per capita income, 1.85%, increases the share of containerized trade between 1.3% and 2%. It is the number of countries using containerization, and not the number of container ports in these countries, that affects usage of the technology. In specification 3, the coefficient for the number of ports in the network is insignificant, and in specification 5, which includes all measures of network effects, it is even negative. In sum, new adoptions by trade partners, their usage of containerization, and their income are important determinants of a country's share of containerized trade after adoption. Note also that the effect of fixed costs is robust to the inclusion of these different network measures.

While Table 5 investigates how decisions by the entire network of trade partners affect a country's usage of containerization, Table 6 investigates the role of its neighbors' decisions (countries that share a land border). The estimations presented in Table 6 include the same explanatory variables as the previous table (not shown), and additionally, they include measures of the number of neighboring countries using containerization, their average usage, and their number of ports. Both adoption and usage by neighboring countries have a positive and significant effect on a country's usage of the technology, even after controlling for the influence of the rest of the network of trade partners. However, the impact is small when compared to that of the entire network. On average, adoption by a neighboring country increases a country's usage of containerization between 0.08% and 0.27%, and a two-standard-deviation increase in neighbors' usage of containerization, 0.45, increases a country's usage of containerization by about 0.18%.

In Tables 7 to 10, I present several robustness checks which address particular concerns about the strength of the previous results. In Table 7, I include additional explanatory variables such as the number of ports per km of coastline, a dummy variable for episodes of banking crisis, and real per capita income. First, the number of ports per km of coastline attempts to control for the extent to which domestic maritime trade matters. Additionally, the number of ports may affect the impact of the domestic transportation network on fixed costs, given that an extensive network of paved roads and railway lines becomes less necessary once there are many ports per km of coastline. Second, by including banking crises as a control variable, I endeavor to exclude the possibility that network effects are being driven by similarity in financial shocks. Episodes of banking crisis create disruptions in credit markets which affect firms' decisions, in

Table 5: Network adoption and usage (ordinary least squares)

	(1)	(2)	(3)	(4)	(5)
Years since adoption	0.026	0.043*	0.102**	0.053*	0.096**
	(0.025)	(0.019)	(0.025)	(0.021)	(0.024)
Years since adoption, sq	-0.002**	-0.002**	-0.002**	-0.002**	-0.002**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
World share leased boxes, t-1	0.048*	0.046**	0.029**	0.028	0.009
	(0.021)	(0.013)	(0.011)	(0.020)	(0.018)
Density of paved roads, t-1	0.215*	0.175+	0.202+	0.117	0.133
	(0.101)	(0.103)	(0.107)	(0.099)	(0.106)
Density of railway lines, t-1	5.794	7.803+	6.889+	7.815+	6.265
	(4.016)	(4.108)	(3.762)	(4.258)	(3.831)
Distance to network, log t-1	-0.250	-0.315	-0.361	-0.285	-0.347
	(0.246)	(0.283)	(0.287)	(0.272)	(0.271)
Trade openness, log t-1	0.291	0.266	0.328	0.212	0.290
	(0.200)	(0.188)	(0.199)	(0.179)	(0.189)
Population, log t-1	0.272	0.256	0.245	0.378	0.422
	(0.346)	(0.344)	(0.330)	(0.353)	(0.335)
Network nr. countries, t-1	1.813*	1.575+	1.774*	0.602	0.431
	(0.867)	(0.897)	(0.889)	(1.094)	(1.100)
Network usage, t-1		1.465*	1.505*	1.287+	1.261+
		(0.682)	(0.663)	(0.675)	(0.637)
Network ports, t-1			-0.028		-0.048+
			(0.022)		(0.025)
Network real GDPpc, log t-1				0.735+	1.120*
				(0.399)	(0.470)
Observations	1504	1501	1501	1501	1501
R^2	0.80	0.80	0.80	0.80	0.81
F-test (p-value)	0.006	0.009	0.006	0.036	0.041

Notes: The dependent variable is the share of containerized trade in logs. All specifications include a constant, country fixed effects, and year fixed effects. The last line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

particular those related to usage of new technologies. To the extent that banking crises propagate internationally, firms in various countries will be experiencing similar financial shocks. Finally, real per capita income controls for market size and the potential for economies of scale. None

Table 6: **Neighbors' adoption and usage (ordinary least squares)**

	(1)	(2)	(3)	(4)	(5)
Network nr. countries (excl. neigh), t-1	1.433	1.784^{+}	1.060	1.250	1.150
	(1.498)	(0.990)	(1.764)	(1.170)	(1.778)
Network usage (excl. neigh), t-1				1.650^{+}	
				(0.938)	
Network ports (excl. neigh), t-1					-0.022
					(0.021)
Network nr. neighbors, t-1	0.274*	0.108	0.186*	0.079	0.187*
	(0.123)	(0.102)	(0.087)	(0.111)	(0.085)
Neighbors usage, t-1		0.385**		0.391*	
		(0.145)		(0.154)	
Neighbors ports, t-1			0.004		0.004
			(0.015)		(0.015)
Observations	1207	1029	1192	1029	1192
R^2	0.81	0.78	0.80	0.79	0.80
F-test (p-value)	0.252	0.584	0.263	0.443	0.365

Notes: The dependent variable is the share of containerized trade in logs. All specifications include a constant, country and year fixed effects, and the same controls as in table 5 ("years since adoption," "years since adoption squared," "world share leased boxes," "distance to network," "density of paved roads," "density of railway lines," "trade openness," and population), not shown. The last line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

of these controls has a significant effect on containerized trade, and all the results presented previously are robust to their inclusion in the estimations.

In Tables 8.(a) and 8.(b), I investigate differences across several sub-samples of countries. Column 1 reproduces specification 2 in Table 5, and columns 2 and 3 estimate the same regression for high to medium-high income countries and low to medium-low income countries, respectively.[59] While network size matters equally for both types of countries,[60] network usage has a stronger effect on containerized trade in low to medium-low income countries than in high to medium-high income countries. In addition, growth in leasing of container boxes also has a stronger effect on containerized trade in the former than in the latter countries. On the

[59] I use the following World Bank income classifications, based on per capita income in 1992: low income, below \$675; medium-low income, between \$676 and \$2,695; medium-high, between \$2,696 and \$8,355; and high income, above \$8,355.

[60] Even though the coefficients of network size are not statistically significant due to an increase in standard errors caused by a smaller sample size, they have the same magnitude as in column 1.

Table 7: **Robustness checks: additional controls (ordinary least squares)**

	(1)	(2)	(3)	(4)
World share leased boxes, t-1	0.046**	0.049*	0.049*	0.034+
	(0.013)	(0.020)	(0.020)	(0.017)
Density of paved roads, t-1	0.175+	0.178+	0.180+	0.095
	(0.103)	(0.104)	(0.102)	(0.143)
Density of railway lines, t-1	7.803+	7.533+	7.565+	6.724+
	(4.108)	(4.332)	(4.293)	(3.900)
Distance to network, log t-1	-0.315	-0.314	-0.309	-0.321
	(0.283)	(0.283)	(0.284)	(0.287)
Trade openness, log t-1	0.266	0.266	0.274	0.216
	(0.188)	(0.188)	(0.193)	(0.213)
Population, log t-1	0.256	0.252	0.249	0.421
	(0.344)	(0.357)	(0.355)	(0.405)
Network nr. countries, t-1	1.575+	1.549	1.506	1.714+
	(0.897)	(0.953)	(0.972)	(0.977)
Network usage, t-1	1.465*	1.469*	1.493*	1.215
	(0.682)	(0.687)	(0.690)	(0.768)
Ports/coastline, t-1		-2.650	-2.718	1.677
		(12.819)	(12.850)	(13.545)
Banking crisis, 5 yrs			0.042	0.049
			(0.046)	(0.045)
Real GDPpc PPP, log t-1				0.359
				(0.257)
Observations	1501	1501	1501	1501
R^2	0.80	0.80	0.80	0.80
F-test (p-value)	0.009	0.012	0.010	0.102

Notes: The dependent variable is the share of containerized trade in logs. All regressions include "years since adoption," "years since adoption squared," a constant, country fixed effects, and year fixed effects (not shown). The last line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

other hand, the domestic transportation network matters more for high to medium-high income countries. The density of paved roads and railway lines are both jointly statistically significant at the 5% level for this group of countries, but not for low to medium-low income countries.

Table 8: **(a) Robustness checks: sub-samples (ordinary least squares)**

	(1)	(2)	(3)
World share leased boxes, t-1	0.046**	0.016	0.041**
	(0.013)	(0.015)	(0.010)
Density of paved roads, t-1	0.175+	0.336*	0.323
	(0.103)	(0.134)	(0.504)
Density of railway lines, t-1	7.803+	1.794	10.958
	(4.108)	(2.945)	(8.155)
Distance to network, log t-1	-0.315	0.046	-0.549
	(0.283)	(0.292)	(0.851)
Trade openness, log t-1	0.266	0.381+	0.392
	(0.188)	(0.191)	(0.302)
Population, log t-1	0.256	0.381	0.297
	(0.344)	(0.439)	(0.686)
Network nr. countries, t-1	1.575+	1.533	1.163
	(0.897)	(0.988)	(1.676)
Network usage, t-1	1.465*	0.136	2.237*
	(0.682)	(0.647)	(0.907)
Observations	1501	791	710
R^2	0.80	0.87	0.78
Nr.countries	77	36	41
F-test (p-value)	0.009	0.013	0.295
Sub-sample	All	High med-high income	Low med-low income

Notes: The dependent variable is the share of containerized trade in logs. All regressions in parts (a) and (b) include "years since adoption," "years since adoption squared," a constant, country fixed effects, and year fixed effects (not shown). The penultimate line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Columns 4 to 7 estimate the same regression excluding island countries, the US, Western Europe, or oil exporters, respectively. All previous results, except for the impact of the density of paved roads, are robust to the exclusion of these countries. When I exclude island countries, the US, or Western Europe from the sample, paved roads are no longer statistically significant *per se* (although the coefficients keep their magnitudes relative to column 1), and while the effect of railway lines remains positive and significant, the density of both paved roads and railway lines are also no longer jointly significant. These results are in line with those in columns 2 and 3, which show that the domestic transportation network matters more for high to medium-high

Table 8: (b) Robustness checks: sub-samples (ordinary least squares)

	(4)	(5)	(6)	(7)
World share leased boxes, t-1	0.086**	0.052**	0.033*	0.049**
	(0.030)	(0.016)	(0.015)	(0.014)
Density of paved roads, t-1	0.200	0.124	0.108	0.145
	(0.229)	(0.125)	(0.170)	(0.107)
Density of railway lines, t-1	8.237+	7.871+	11.334	7.507+
	(4.621)	(4.485)	(9.393)	(4.327)
Distance to network, log t-1	-0.268	-0.307	-0.324	-0.517+
	(0.314)	(0.281)	(0.362)	(0.300)
Trade openness, log t-1	0.291	0.272	0.370+	0.112
	(0.246)	(0.190)	(0.215)	(0.160)
Population, log t-1	0.323	0.270	0.081	0.281
	(0.460)	(0.384)	(0.377)	(0.362)
Network nr. countries, t-1	1.375	1.565+	1.230	2.132*
	(1.004)	(0.932)	(1.196)	(0.912)
Network usage, t-1	1.837*	1.341*	1.831*	1.050+
	(0.896)	(0.658)	(0.836)	(0.576)
Observations	1147	1463	1164	1415
R^2	0.80	0.80	0.79	0.83
Nr.countries	62	76	64	71
F-test (p-value)	0.213	0.106	0.251	0.035
Sub-sample	Excl. islands	Excl. US	Excl. Western Europe	Excl. oil exporters

income countries, such as the US, Western Europe, and the United Kingdom (an island country), than for low to medium-low income countries.

So far, I have not considered the potential for endogeneity in my previous results. However, interpretation of the coefficients of network effects may suffer from what Manski calls "the reflection problem."[61] First, network effects may arise from similarity in trade partners' characteristics and institutions. Second, if two countries affect each other simultaneously, it is hard to identify empirically the actual causal effect that the behavior of a country's network of trade partners has on an individual country's behavior.

I address this problem with two additional robustness tests, presented in Tables 9 and 10. First, I consider larger lags for the explanatory variables. Two- and five-year lagged values for the

[61] Manski (1993) is the first formal discussion of identification problems in the context of models with social interactions. In demonstrating the importance of peer effects among Dartmouth roommates, Sacerdote (2001) also discusses in detail the difficulties of interpreting coefficients for social interactions. He solves the reflection problem by exploring freshman random assignment to dorms and roommates.

Table 9: Robustness checks: increased time lags (ordinary least squares)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		2-year lags				**5-year lags**		
Share leased boxes	0.036**	0.050**	0.052**	0.015	0.026+	0.062**	0.029*	0.025
	(0.013)	(0.016)	(0.015)	(0.023)	(0.015)	(0.015)	(0.011)	(0.021)
Density paved roads	0.148	0.117	0.146	0.054	0.084	0.070	0.115	0.032
	(0.111)	(0.117)	(0.121)	(0.112)	(0.128)	(0.136)	(0.141)	(0.139)
Density railway lines	5.139	6.639+	5.695	7.002+	7.010+	7.976*	7.388*	7.687+
	(3.921)	(3.653)	(3.430)	(3.884)	(3.770)	(3.535)	(3.345)	(3.870)
Distance to network	-0.265	-0.340	-0.386	-0.302	-0.486+	-0.539+	-0.592*	-0.508
	(0.229)	(0.286)	(0.293)	(0.275)	(0.255)	(0.305)	(0.296)	(0.313)
Network nr countries	1.905*	1.733+	1.935*	0.733	1.867*	1.801*	2.109*	1.074
	(0.920)	(0.960)	(0.964)	(1.078)	(0.823)	(0.852)	(0.859)	(0.878)
Network usage		1.289+	1.330*	1.047		0.884	0.905	0.628
		(0.673)	(0.660)	(0.662)		(0.698)	(0.692)	(0.675)
Network ports			-0.029				-0.039	
			(0.023)				(0.026)	
Network GDP				0.785+				0.574
				(0.424)				(0.447)
Observations	1546	1543	1543	1543	1545	1542	1542	1542
R^2	0.80	0.80	0.80	0.80	0.80	0.79	0.80	0.79
F-test (p-value)	0.076	0.058	0.054	0.141	0.136	0.076	0.071	0.145

Notes: All specifications include a constant, country and year fixed effects, "years since adoption," "years since adoption squared," "trade openness," and population (not shown). The last line presents the p-value of the F-test for the joint significance of the density of paved roads and the density of railway lines. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

network variables, instead of one-year, mitigate the simultaneity problem because a country's decision to increase usage of containerization (an aggregate of its firms' individual decisions) should not influence its trade partners' adoption and usage decisions in the previous two and five years. Table 9 shows that previous results are robust to using larger lags. However, while this strategy mitigates the simultaneity problem, it does not address it fully. The identification problem may still be present if countries affect each other through expectations about their future actions. Therefore, I employ an additional robustness check, which uses the network's domestic transportation infrastructure as an instrument for its usage. This instrument, which is both relevant and exogenous, creates an exogenous source of variation that helps identify network effects. We have seen in previous estimations that a country's density of paved roads and railway lines affects its own usage of containerization. That being the case, the network's density of paved roads and railway lines should also affect the network's usage (the instrument is relevant). The exclusion restriction implies that, conditional on other control variables included in the regression, the network's density of paved roads and railway lines should have no effect on a country's usage of containerization (directly by itself or through an omitted variable), other than its effect through network usage. The main concern with this restriction is that the density of paved roads and railway lines in a country's network could affect the country's usage of containerization directly, either because domestic firms care about the transportation network in trade-partner countries or because expectations about foreign firms' future usage of containerization affect a country's decisions about its domestic transportation network today. Regarding the first concern, it seem unlikely that a seller would care about the costs associated with transporting goods from the port of destination to the final inland destination. This is because the terms of sale between buyers and sellers in international trade usually involve the seller being responsible for the transport of goods either to the port of shipment ("free on board," or "f.o.b.") or to the port of destination ("cost, insurance and freight," or "c.i.f."), and not to their final inland destination. These inland transportation costs at the importer's end are only relevant to the extent that they affect foreign firms' usage of containerization. As for the second concern, investments in roads and railway lines tend to be relatively large and lumpy, and the decision process is usually a long one. Therefore, it seems implausible that expectations about future changes in a foreign country's usage of containerization would affect the average density of roads and railway lines in its network. Nonetheless, and as an additional check for the validity of the exclusion restriction, I regressed the residuals from each IV-2SLS estimation on the instrumental variable(s) and found no statistically significant effects.

Table 10 presents the results from the IV-2SLS estimations, together with their analogous OLS estimations. Using the IV-2SLS method, network effects have an even stronger impact on containerized trade than using OLS. These larger estimates suggest that bias due to measurement error in network usage is likely to be larger in magnitude than the endogeneity bias, which is presumably positive. The IV-2SLS results show that a two-standard deviation increase in network usage increases the share of containerized trade between 2.4% and 3.8%. To put these numbers into context: the mean share of containerized trade in the sample is 25.5%, thus, a half percentage point increase in the average country's network's usage causes its individual usage to increase to between 32.7% and 37%. The first-stage relationship between network density of paved roads and railway lines and network usage is strongly positive, and the F-statistic in all IV-2SLS estimations is large.

4.2.2 Hazard of Adoption

Tables 11 to 15 show the results from estimating the logistic discrete-time hazard presented in equation (32). The dependent variable is constructed in two steps. First, I set the adoption indicator variable equal to one in year t if 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. Since imputed containerized trade is measured with sampling error,

Table 10: Robustness checks: IV-2SLS estimation

	(1) OLS	(2) IV-2SLS	(3) IV-2SLS	(4) IV-2SLS	(5) OLS	(6) IV-2SLS
Years since adoption	0.043*	-0.007	-0.041	-0.011	0.051**	-0.023
	(0.019)	(0.093)	(0.090)	(0.073)	(0.018)	(0.065)
Years since adoption, sq	-0.002**	-0.002**	-0.002**	-0.002**	-0.002**	-0.002**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
World share leased boxes, t-1	0.046**	0.087+	-0.313+	-0.260+	0.065**	-0.289**
	(0.013)	(0.046)	(0.166)	(0.142)	(0.008)	(0.111)
Distance to network, log t-1	-0.315	-0.433	-0.540	-0.490	-0.164	-0.479
	(0.283)	(0.307)	(0.343)	(0.319)	(0.234)	(0.323)
Density of paved roads, t-1	0.175+	0.055	-0.043	0.002	0.161	-0.023
	(0.103)	(0.151)	(0.193)	(0.168)	(0.098)	(0.168)
Density of railway lines, t-1	7.803+	14.255+	19.486+	17.054+	5.460	17.671*
	(4.108)	(7.476)	(10.557)	(8.728)	(3.722)	(8.752)
Trade openness, log t-1	0.266	0.202	0.148	0.173	0.318+	0.173
	(0.188)	(0.165)	(0.192)	(0.174)	(0.182)	(0.184)
Population, log t-1	0.256	0.227	0.206	0.216	0.150	0.186
	(0.344)	(0.373)	(0.458)	(0.414)	(0.338)	(0.432)
Network nr. countries, t-1	1.575+	0.844	0.248	0.525		
	(0.897)	(1.140)	(1.116)	(1.088)		
Network usage, t-1	1.465*	5.665	9.062+	7.482*	1.792**	8.340**
	(0.682)	(3.601)	(4.635)	(3.770)	(0.628)	(2.941)
First-stage (dependent variable: Network usage, t-1)						
Network rail density, t-2		1.357*		0.941		1.168*
		(0.567)		(0.600)		(0.500)
Network roads density, t-2			0.069*	0.051+		0.055+
			(0.028)	(0.029)		(0.030)
Observations		1497	1497	1497		1497
F-stat		143.218	40.366	43.335		34.947

Notes: All regressions include a constant, country fixed effects, and year fixed effects. Standard errors in parentheses, clustered by country. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

I estimate the standard errors by bootstrapping the results 1000 times.[62] The explanatory

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

variables are lagged 5 years in order to account for the time it takes to build a container port once the decision to construct it has been made.[63]

Figure 6: Expected containerized trade over different time horizons

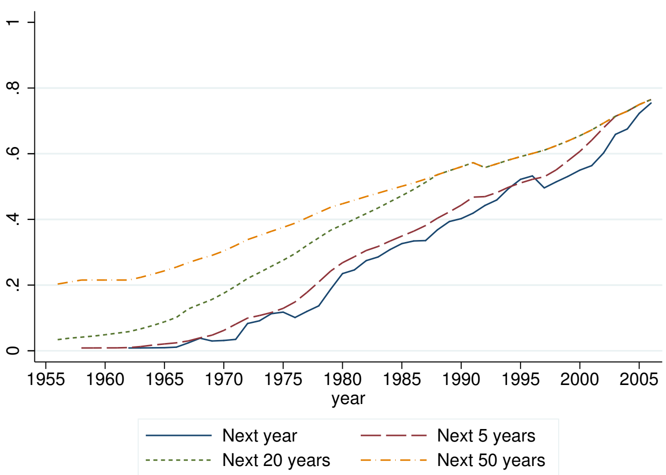


Table 11 presents estimates of equation (32) where the expected share of containerized trade is computed over different time horizons: 5 years, 20 years, and 50 years. The idea is to test the time-period that policymakers use in their adoption decisions.[64] The coefficients in columns 1 to 3 show that, for all time horizons, the impact of expected containerized trade on the hazard of adoption is very strong. For example, a 1% increase in expected containerized trade over a 20-year period makes a country 4.3 times more likely to adopt containerization (exp(1.459)). These results are in line with the theoretical predictions presented in Section 3. Even though the coefficient for expected containerized trade over a 20-year period is larger than the others, the distinction between time horizons appears not to be noteworthy for policymakers deciding whether or not to adopt containerization.[65]

All specifications include dummies for the four periods identified in the historical analysis in Section 2. Instead of a linear specification (or even a polynomial or Weibull) for time, I use this set of dummy variables to allow a more flexible estimation of the baseline logit hazard function.

[63] In the *Containerisation International* yearbooks, there are various notes explaining both the current situation and future plans for each port. For example, they read: "new terminal under construction... operational at (year)," "(y) is to have a container terminal and one berth ready by (year)," "a new terminal was to be completed by the end of (year)." By looking at these notes, I estimate that, on average, a container terminal takes about 3 to 5 years to be ready after the initial notice of its construction. Adding an extra year for the information to be updated in the *Containerisation International* yearbooks makes it an average of 5 years between the decision to build the terminal and it being ready.

[64] Figure 6 depicts average expected containerized trade over these different time horizons.

[65] It would be interesting to run a regression with all three variables, but since they are highly correlated with each other (the correlation coefficients are between 0.87 and 0.97), they would not deliver valid estimates of the partial effect of these variables (Wooldridge, 2009, Chapter 4).

Table 11: Adoption of containerization (logistic discrete-time hazard)

	(1)	(2)	(3)
Exp. containerized trade, avg. first 5-years, log t-5	0.767**		
	(0.235)		
Exp. containerized trade, avg. first 20-years, log t-5		1.459**	
		(0.307)	
Exp. containerized trade, avg. first 50-years, log t-5			1.317**
			(0.386)
Real GDPpc PPP, log t-5	0.099	0.092	0.091
	(0.154)	(0.153)	(0.154)
Share world trade, real t-5	0.299**	0.288**	0.257**
	(0.091)	(0.091)	(0.080)
Area km2, log	0.194*	0.230**	0.214*
	(0.087)	(0.087)	(0.092)
Oil exporter	-0.919	-1.226	-1.002
	(0.790)	(0.816)	(0.794)
Dummy 1956-1965	-1.668	-1.602	-3.430**
	(1.518)	(1.630)	(1.322)
Dummy 1966-1974	2.388**	2.805**	1.254*
	(0.870)	(0.771)	(0.621)
Dummy 1975-1983	2.964**	3.322**	2.409**
	(0.712)	(0.674)	(0.600)
Constant	-5.226**	-5.289**	-5.283**
	(1.731)	(1.781)	(1.734)
Observations	875	997	997
Log-likelihood	-221.564	-214.910	-222.813

Notes: 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. Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

As a group, they identify the baseline hazard, while their individual coefficients allow a different value of the logit hazard in each specific time period. The estimates for these period dummies show that the baseline hazard increases over time; that is, factors affecting all countries together cause the likelihood of adoption to increase over time.

Other explanatory variables in Table 11 are per capita income, a country's share in world trade, geographical area, and a dummy for oil exporter. A country's share in world trade has a positive and significant effect on the hazard of adoption: a one percentage point increase in its share in world trade makes a country 30% more likely to adopt. Countries with larger geographical areas are also more likely to adopt containerization: a country that is 10% larger than another is between 7 and 10 times more likely to adopt. Since oil is not containerizable, countries that rely heavily on oil exports should be less likely to adopt containerization; and in fact, estimates show that oil exporters are between 2.5 and 3.4 times less likely to adopt containerization than other countries.

While I would expect per capita income to have a negative impact on adoption, given that richer countries tend to have higher labor costs, its coefficients are positive and insignificant. One possible reason why this is the case is that richer countries also have better institutions which influence political costs associated with building a container port. In Table 12, I control for institutional barriers by adding three measures of institutional quality: executive constraints, rule of law, and judicial efficiency.[66] Both rule of law and judiciary efficiency have a positive impact on adoption. Their estimated odds ratio in column 4 are 1.56 and 1.43, respectively, which implies that a one unit increase in either of these institutional indices causes a country to be about 50% more likely to adopt containerization. Notice, also, that the coefficients of per capita income decrease when I add institutional variables, and some even become negative, which suggests that this variable is in fact capturing a mix of labor costs and institutions. All other coefficients remain the same.

In Table 13, I include another set of regressors, this time to analyze the role of trade with early adopters (the United States, Australia, Belgium, the Netherlands, and the United Kingdom). These estimates provide a test of these countries' role in leading the international diffusion of containerization. They evaluate the role of trade as a vehicle for transmission of a new technology and as a measure of the potential for economies of scale. Since the US was the first country to adopt containerization, and the only country using the technology from 1956 to 1965, I start by adding trade with the US only (column 1), and then go on to add trade with other early adopters (columns 2 and 3). Column 3 replicates column 2, but it includes two additional controls, an island dummy and the length of coastline. These variables are meant to control for the importance of domestic maritime trade.[67] Surprisingly, column 1 shows that countries that trade more with the US are less likely to adopt containerization. A possible reason for this result is competition. Countries with less productive firms may want to protect their local markets from American competition by being out of the container network. However, since adding trade with other countries makes this result disappear, it is plausible that trade with the US simply has no effect on adoption. Nevertheless, this is still a surprising result, given that the US is not only the first adopter but is also the largest user of containerization. In Table 14, I test if this unexpected result is due to the effect of Canada and Mexico, two countries which trade mainly with the US, but mostly by land. Excluding Canada and Mexico from the estimations does not change the previous results.

[66] In this and in the following two tables, I focus on estimations using expected containerized trade over a 20-year time period. Section G of the Appendix show similar results using 5- and 50- year horizons.

[67] I also added a dummy for the period when the Suez Canal was closed, but nothing changed because the dummy for the period 1966–1974 almost coincides with that closure.

Table 12: Additional controls (20-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 20 yrs	1.452**	1.877**	1.662**	1.968**
	(0.315)	(0.435)	(0.332)	(0.477)
Real GDPpc PPP, log t-5	0.084	-0.236	-0.037	-0.263
	(0.163)	(0.180)	(0.172)	(0.184)
Share world trade, real t-5	0.276**	0.107	0.172+	0.076
	(0.092)	(0.101)	(0.093)	(0.096)
Area km2, log	0.235*	0.270*	0.291*	0.313**
	(0.095)	(0.119)	(0.113)	(0.115)
Oil exporter	-1.256	-1.662+	-1.248	-1.587
	(0.781)	(0.921)	(0.818)	(1.009)
Executive constraints, log t-5	0.041	0.047	-0.034	-0.003
	(0.062)	(0.077)	(0.076)	(0.075)
Rule of law		0.560**		0.440**
		(0.155)		(0.156)
Efficiency of judiciary			0.550**	0.358*
			(0.179)	(0.159)
Dummy 1956-1965	-1.617	-1.293	-1.492	-1.363
	(1.685)	(1.226)	(1.309)	(1.134)
Dummy 1966-1974	2.759**	3.115**	2.909**	3.250**
	(0.819)	(0.900)	(0.823)	(0.960)
Dummy 1975-1983	3.277**	3.834**	3.576**	4.004**
	(0.704)	(0.767)	(0.724)	(0.846)
Observations	997	997	997	997
Log-likelihood	-214.590	-202.221	-206.009	-198.727

Notes: 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. All specifications include a constant and period dummies (not shown). Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Columns 2 and 3 show that trade with Australia and the United Kingdom have strong positive impacts on a country's hazard of adoption. Increasing trade with Australia by one billion dollars makes a country between 427 and 535 times more likely to adopt. This is a very strong effect. Since Australia is geographically one of the most remote countries in the sample, it suggests that containerization allows substantial gains for trade over long distances. The impact

Table 13: Additional controls (20-year horizon)

	(1)	(2)	(3)
Exp. containerized trade, 20 yrs	1.927**	1.871**	1.854**
	(0.463)	(0.652)	(0.649)
Real GDPpc PPP, log t-5	-0.067	-0.065	-0.249
	(0.184)	(0.229)	(0.259)
Share world trade, real t-5	0.175*	-0.698	-0.815$^+$
	(0.088)	(0.465)	(0.468)
Area km2, log	0.306**	0.210	-0.015
	(0.106)	(0.140)	(0.235)
Oil exporter	-1.276	-1.179	-1.111
	(1.017)	(1.358)	(1.438)
Executive constraints, log t-5	0.026	-0.098	-0.136
	(0.082)	(0.098)	(0.110)
Rule of law	0.425**	0.289	0.245
	(0.150)	(0.210)	(0.211)
Efficiency of judiciary	0.293$^+$	0.217	0.321$^+$
	(0.160)	(0.177)	(0.194)
Trade with USA, t-5	-0.265$^+$	0.035	0.036
	(0.140)	(0.236)	(0.219)
Trade with AUS, t-5		6.283$^+$	6.057*
		(3.233)	(3.025)
Trade with BEL, t-5		-0.624	0.002
		(6.232)	(5.580)
Trade with NLD, t-5		6.881	6.840
		(5.169)	(5.031)
Trade with GBR, t-5		1.413$^+$	1.564*
		(0.770)	(0.777)
Island			-0.505
			(0.832)
Km of coastline, log			0.408$^+$
			(0.245)
Observations	980	579	536
Log-likelihood	-186.980	-149.043	-144.578

Notes: See Table 12.

of trade with the UK is not nearly as large, but it is still notable. Each extra billion dollar of trade with the UK makes a country between 4 and 5 times more likely to adopt.

Tables 14 and 15 present the same estimations as in columns 1 and 2 of Table 13 using different sub-samples of countries. The idea is to test whether or not particular groups of countries are driving the previous results. Columns 1 and 2 exclude Canada and Mexico, as discussed above, columns 3 and 4 exclude the main Commonwealth countries apart from the UK,[68] columns 5 and 6 exclude Australia's main trade partners (Japan, China, and New Zealand), and columns 7 and 8 exclude oil exporters. Even though there are a few cases in which the coefficients for trade with Australia and the UK are not statistically significant, they keep the same sign and magnitude as in previous estimations. Excluding Australia's main trade partners from the sample raises the impact of trade with Australia, which suggests that Australia's role in the diffusion of containerization is not limited to its main trade partners.

To summarize, the main findings in this section are that expected future containerized trade, institutions, a country's trade and geographical size, and trade with Australia and the United Kingdom are the main determinants of adoption. Trade with the United States, surprisingly, has no effect.

5 Conclusion

Containerization was the most important innovation 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 perspectives, adoption of container-port infrastructure and effective use of this technology in international trade. I develop a theoretical model that is consistent with the diffusion patterns observed in the data and relevant historical features of containerization. Adoption, which follows an S-shaped path, is determined in particular by the cost of adoption, country size, and predicted containerized trade. Fixed costs and network effects determine firms' usage of containerization and therefore the share of trade that is containerized.

I then take the predictions of the model to the data. The empirical results are consistent with the model and show that adoption depends on institutional barriers, country size (both in terms of trade and geographical area), trade with Australia and the United Kingdom, and expected future usage of containerization. On the other hand, usage of containerization is determined by fixed costs, which are associated with the spread of leasing companies and the domestic land transportation infrastructure; network effects, measured by network size, network usage, and network income; and neighbor effects. While network usage and the spread of leasing companies have a stronger impact on low to medium-low income countries than high to medium-high income countries, the domestic land transportation infrastructure matters more for the latter than for the former.

These findings have important implications for previous literature and the role of government policy in hastening a country's integration into the global economy. First, my analysis has political economy implications. By highlighting the role of institutional barriers in delaying adoption of containerization, it sheds light on the connection between institutional quality and international trade.

[68] These are Australia, Canada, India, New Zealand, Singapore, and South Africa.

Table 14: Robustness checks: sub-samples (20-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 20 yrs	2.025**	1.795**	1.999**	1.784*
	(0.505)	(0.670)	(0.549)	(0.698)
Real GDPpc PPP, log t-5	-0.088	-0.057	-0.149	-0.015
	(0.181)	(0.248)	(0.178)	(0.251)
Share world trade, real t-5	0.149	-0.718	0.208	-0.935
	(0.118)	(0.683)	(0.177)	(0.677)
Area km2, log	0.319**	0.203	0.209	0.167
	(0.110)	(0.146)	(0.131)	(0.143)
Oil exporter	-1.929	-0.908	-1.678	-1.009
	(1.891)	(2.827)	(1.235)	(1.637)
Executive constraints, log t-5	0.025	-0.094	-0.015	-0.131
	(0.079)	(0.094)	(0.083)	(0.097)
Rule of law	0.450**	0.272	0.448*	0.247
	(0.169)	(0.235)	(0.194)	(0.269)
Efficiency of judiciary	0.305+	0.211	0.296+	0.169
	(0.164)	(0.192)	(0.171)	(0.190)
Trade with USA, t-5	-0.009	-0.052	-0.036	0.013
	(0.391)	(0.583)	(0.237)	(0.289)
Trade with AUS, t-5		6.720		7.758+
		(4.162)		(4.187)
Trade with BEL, t-5		-0.694		0.115
		(6.432)		(6.042)
Trade with NLD, t-5		7.375		6.307
		(5.989)		(5.827)
Trade with GBR, t-5		1.366+		2.441
		(0.776)		(1.859)
Observations	951	560	706	559
Log-likelihood	-180.858	-145.012	-173.094	-139.975
Sub-sample	Excl. CAN & MEX	Excl. CAN & MEX	Excl Common-wealth	Excl Common-wealth

Notes: See Table 12.

Table 15: Robustness checks: sub-samples (20-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 20 yrs	1.883**	1.702**	2.204**	2.316**
	(0.512)	(0.645)	(0.403)	(0.534)
Real GDPpc PPP, log t-5	0.067	0.117	-0.035	-0.025
	(0.200)	(0.253)	(0.183)	(0.250)
Share world trade, real t-5	0.163+	-0.838+	0.171+	-0.814
	(0.089)	(0.499)	(0.094)	(0.515)
Area km2, log	0.198+	0.163	0.325**	0.264+
	(0.112)	(0.160)	(0.116)	(0.140)
Oil exporter	-1.267	-1.078		
	(0.988)	(1.297)		
Executive constraints, log t-5	0.005	-0.116	0.017	-0.099
	(0.074)	(0.100)	(0.080)	(0.102)
Rule of law	0.387**	0.272	0.505**	0.419*
	(0.148)	(0.225)	(0.150)	(0.199)
Efficiency of judiciary	0.223	0.241	0.270	0.210
	(0.157)	(0.188)	(0.165)	(0.182)
Trade with USA, t-5	-0.238	0.069	-0.272+	0.094
	(0.151)	(0.225)	(0.156)	(0.270)
Trade with AUS, t-5		13.139+		6.682*
		(7.514)		(3.339)
Trade with BEL, t-5		-0.730		-0.217
		(5.971)		(6.314)
Trade with NLD, t-5		6.459		6.972
		(5.057)		(5.497)
Trade with GBR, t-5		1.219		1.277+
		(0.846)		(0.744)
Observations	958	567	948	557
Log-likelihood	-177.680	-141.583	-172.785	-135.694
Sub-sample	Excl NZL, CHN & JPN	Excl NZL, CHN & JPN	Excl. oil exp.	Excl. oil exp.

Notes: See Table 12.

Second, my results emphasize an important barrier to trade: internal trade costs. While the bulk of the international trade literature has focused its attention on international barriers to trade, especially barriers related to geographical frictions and national borders, the role of internal trade costs has been less studied. This paper shows that internal trade costs (associated with the domestic land transportation network) played an important role in accelerating the diffusion of containerization. This suggests that improvements in the domestic transportation network can have important consequences for not only domestic but also international trade costs. As a result, government policies, which are distinct from the usual trade-policy instruments, can have significant effects on international trade, for example by enhancing intermodality.

Finally, my results also point to the relevance of trade linkages. Network effects are strong, and the diffusion of containerization is faster in countries with substantial trade with containerized countries. In addition, countries trading with rich countries, in particular Australia and the United Kingdom, adopt faster. Trade partners mattered greatly in the diffusion of containerization. This suggests that developing countries seeking to extend their global economic integration can benefit from trading with richer countries and with countries that are in the center of the international trade system.

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Appendices

A Information Sources

A.1 Containerization Dataset

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
  - Publisher: Informa UK Ltd., London, UK
  - Years: 1968, 1970–2010
  - Description: Each yearbook consists of a detailed directory of all container ports in the previous year. For each port, it provides full contact details, verbal descriptions of current and planned facilities (berths, terminals facilities, and rail facilities), container service providers, and container handling statistics. However, there is more statistical information in later yearbooks than in earlier ones.

- *Lloyd's Ports of the World*
  - Publisher: Shipping World, London, UK (1946–1981); Lloyd's of London Press, Colchester, Essex, UK (1982–)
  - Years: 1946–1996
  - Description: Each book contains a comprehensive list of all the ports in the world. For each port, there is detailed nautical information, a description of its principal facilities and geographical characteristics, and contact details.

- *Shipping Statistics* yearbooks
  - Publisher: Institute of Shipping Economics and Logistics, Bremen, Germany
  - Years: 1968, 1975, 1977, 1979, 1981, 1984, 1986–2009
  - Description: Each yearbook provides detailed statistical surveys for the entire maritime industry. It contains a section, "Port Surveys," with detailed port statistics for a large number of ports worldwide. 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).

A.2 Maritime Distances

- *Reeds Marine Distance Tables: 59,000 Distances and 500 Ports Around the World*
  - Publisher: Adlard Coles Nautical, London, UK
  - Year: 2010 (11th ed.)
  - Description: 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.

B Coding Rules

B.1 Adoption of Containerization

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.

B.2 Usage of 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 regardless of whether it was containerized or not (in shipping jargon, general cargo trade). 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. Section D explains my strategy to aggregate these shares of containerized trade across all ports in each country.

B.3 Maritime Distances

For each country, I identify up to 3 main ports. These are ports that handled the largest volume of trade (containerized and bulk) in any two consecutive years. I then calculate the distances between all countries as the minimum maritime distance between their main ports. I use bilateral ocean distances given in the Reeds tables (see Appendix A). For port-pairs not listed in the Reeds tables, I use the closest international hub as a connection point. I use the following 8 major hubs, which ranked top 5 among the world's largest container ports, by volume of container traffic, in 1975, 1983, or 2000 (source: *Containerisation International* yearbooks): Busan (South Korea), Hong Kong (Hong Kong SAR), Kaohsiung (Taiwan), Kobe (Japan), New York (USA), Oakland (USA), Rotterdam (Netherlands), and Singapore (Singapore). While, ideally, I should have used the largest ports regardless of cargo type, the fact that many of these ports are also large hubs for bulk trade makes this a fairly good set of international hubs.

C Country Coverage

C.1 Adoption of Containerization

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.

C.2 Usage of Containerization

Argentina, Australia, Bahrain, Bangladesh, Belgium, Benin, Brazil, Bulgaria, Cambodia, Canada, Cameroon, Chile, China, Colombia, Congo (Republic), Costa Rica, Croatia, Cyprus, Denmark, Djibouti, Ecuador, Egypt, El Salvador, Estonia, Fiji, Finland, France, Gabon, Georgia, Germany, Ghana, Greece, Guadeloupe, Guatemala, Haiti, Honduras, Iceland, India, Indonesia, Ireland, Israel, Italy, Ivory Coast, Jamaica, Japan, Jordan, Kenya, Kuwait, Latvia, Lithuania, Malaysia, Mauritius, Mexico, Morocco, Netherlands, Netherlands Antilles, New Caledonia, New Zealand, Nigeria, Norway, Oman, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Qatar, Reunion, Romania, Russia, Saudi Arabia, Senegal, Singapore, Slovenia, Solomon Is., Somalia, South Africa, South Korea, Spain, Sri Lanka, Sudan, Sweden, Syria, Tanzania, Thailand, Togo, Tunisia, Turkey, United Arab Emirates, United Kingdom, Ukraine, Uruguay, USA, Venezuela, Vietnam, Yemen, and Yugoslavia.

D Missing Data, Imputation and Aggregation

In this section, I explain my strategies for imputing missing values and aggregating port-level data by country.

Containerized trade by port

- For each port, I estimate the following equation using OLS and a bayesian approach based on Markov chain Monte Carlo (MCMC) simulation:

$$\text{containerized trade}_t = \beta_0 + \beta_1 \{\text{TEUs}\}_t + \beta_2 t + \epsilon_t$$

- R-squares are reasonably high for most ports, and MCMC predictions are not significantly dissimilar from OLS.
- Only those missing values for which both techniques produce similar predictions, namely where the difference between the OLS and MCMC predictions is smaller than one standard deviation of all available data for each port, are considered valid.
- For these valid predictions, my imputed value is the average of the OLS and MCMC predictions.
- This criteria generates a total of 378 imputed values (75 values remain missing), which is 4.2% of the entire dataset.

Share of general cargo (out of total trade)

- I calculate each country's share of general cargo trade as the weighted average share of general cargo trade across its ports using port total trade as weights. (I include only ports with data on total trade.)
- I then use this weighted share of general cargo trade to estimate the following equation for each country, again using OLS and MCMC:

$$\begin{aligned}\text{share general cargo}_t &= \beta_0 + \beta_1\{\text{GDP industry share}\}_t \\ &\quad + \beta_2\{\text{total trade}\}_t + \beta_3 t + \epsilon_t\end{aligned}$$

- The same criteria for selecting valid predictions as for "containerized trade by port" generates 198 imputed values (81 remain missing), which is 6.2% of the entire dataset.

Share of containerized general cargo trade

- The share of containerized general cargo trade in each country is defined as

$$share/degree = \frac{\text{total containerized trade}}{\text{share of general cargo} \times \text{total trade}}$$

- I only use ports with complete data, so that there is no imbalance between ports included in aggregated containerized trade and ports included in aggregated total trade.
- Since units of measurement are completely different between New Zealand's ports (and even within the same port in different years), I calculate a TEU-weighted average share of containerized trade for this country only.
- In order to ensure that my measure of the share of containerized general cargo trade is representative of the country's real usage of containerization, I delete those values that were calculated using only ports that cumulatively account for less than 20% of the country's total general cargo trade.
- In the end, there are 160 values for the share of containerized general cargo trade (across 37 countries) that were calculated using imputed data. Overall, my dataset contains data on the share of containerized general cargo trade for 102 countries between 1956 and 2008.

E Adoption Years

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, Hong Kong SAR, Israel, Ivory Coast, Poland, Portugal, Yugoslavia
1971	Brazil, Colombia, Greece, India, Philippines, South Africa, USSR
1972	Bahamas, Bulgaria
1973	Cameroon, Chile, Iceland, Trinidad and Tobago
1975	Barbados, Honduras, Indonesia, Kenya, Mozambique, South Korea, Tanzania, Thailand

1976	Aruba, Benin, Dominican Republic, Guatemala, Haiti, Jordan, Mexico, Panama, Saudi Arabia, UAE
1977	Argentina, 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 Is, Austria, Gambia, Mauritania, Montserrat, Myanmar, Tuvalu
1983	Bermuda, Ethiopia, Guinea, US Virgin Is
1985	Senegal
1989	Iraq
1992	Latvia, Reunion
1993	Estonia
1995	Lithuania
1998	Cayman Is
2000	Cuba, Vietnam
2001	French Guiana
2002	Georgia, Kiribati
2003	Cambodia

Notes:

Non-adopters: Gabon, Solomon Is, Somalia.

New countries (there was already a container port in these countries before independence; independence year 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 (countries which gained new territory where a container port already existed): Eritrea (1994, from Ethiopia) and Namibia (1995, from South Africa).

F Definitions and Sources

Area: Total area, in square km (sources: Central Intelligence Agency, 1990, 2011)

Banking Crisis: Episode of systematic banking crisis as defined in Laeven and Valencia (2010) (source: database accompanying the paper Laeven & Valencia, 2010)

Bilateral Trade: Imports and exports, in dollars (source: *Direction of Trade Statistics*, 2012)

Coastline: Length of coastline, in km (sources: Central Intelligence Agency, 1990, 2011)

CPI: Consumer Price Index (source: www.freelunch.com)

Distance to network: Weighted-average maritime distance to other countries in the container network. I use the shortest distance between any two country's main ports. The weights are obtained using 5-year average bilateral trade shares, in real dollars. (sources: Reynolds & Caney, 2010, *Direction of Trade Statistics*, 2012, and `www.freelunch.com`)

GDP: Real GDP in PPP dollars (source: Heston, Summers, & Aten, 2011)

Judicial efficiency: Efficiency of the judiciary system; scaled from 1 to 10 (source: La Porta et al., 1998)

Network variables: See Table 2 for definitions. (sources: author's containerization dataset, Heston et al., 2011, *Direction of Trade Statistics*, 2012, and `www.freelunch.com`)

Oil exporter: Dummy variable that equals one if a country's fuel exports are larger than 2/3 of merchandise exports (source: *World Development Indicators*, 2011)

Paved roads: Length of paved roads, in km (source: Canning, 1998)

POP: Population (source: Heston et al., 2011)

Rail lines: Length of rail lines, in km (source: Canning, 1998)

Rule of law: Rule of law; scaled from 1 to 10. (source: La Porta et al., 1998)

Share world trade: A country's total imports and exports over world's imports and exports. (sources: *Direction of Trade Statistics*, 2012)

Share leased boxes: Share of the world's "box fleet" on operating lease (sources: National Magazine Co., 1983 and 2009)

Trade Openness: Total imports and exports over GDP (sources: *Direction of Trade Statistics*, 2012 and Heston et al., 2011)

XCONST: Executive Constraints constraints on the decision-making powers of chief executives; scaled from 1 to 7. (source: Polity IV, `www.systemicpeace.org`)

G Additional Results

Table G.1: Additional controls (5-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 5 yrs	0.756**	1.110**	0.931**	1.215**
	(0.247)	(0.344)	(0.270)	(0.332)
Real GDPpc PPP, log t-5	0.081	-0.214	-0.014	-0.249
	(0.158)	(0.175)	(0.156)	(0.180)
Share world trade, real t-5	0.279**	0.137	0.190+	0.105
	(0.089)	(0.094)	(0.099)	(0.095)
Area km2, log	0.202*	0.207+	0.239*	0.229*
	(0.096)	(0.116)	(0.115)	(0.107)
Oil exporter	-1.010	-1.449	-0.981	-1.375
	(0.759)	(1.035)	(0.856)	(0.969)
Executive constraints, log t-5	0.071	0.074	0.009	0.025
	(0.064)	(0.073)	(0.077)	(0.073)
Rule of law		0.506**		0.409**
		(0.154)		(0.143)
Efficiency of judiciary			0.485**	0.335*
			(0.178)	(0.156)
Dummy 1956-1965	-1.711	-0.988	-1.410	-0.883
	(1.567)	(1.259)	(1.456)	(1.245)
Dummy 1966-1974	2.293*	2.954**	2.604**	3.194**
	(0.935)	(1.090)	(1.003)	(1.059)
Dummy 1975-1983	2.896**	3.515**	3.220**	3.731**
	(0.761)	(0.879)	(0.803)	(0.871)
Observations	875	875	875	875
Log-likelihood	-220.655	-211.138	-214.270	-208.156

Notes: 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. All specifications include a constant and period dummies (not shown). Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Table G.2: Additional controls (5-year horizon)

	(1)	(2)	(3)
Exp. containerized trade, 5 yrs	1.310**	1.234*	1.277*
	(0.362)	(0.493)	(0.524)
Real GDPpc PPP, log t-5	-0.078	-0.083	-0.243
	(0.178)	(0.238)	(0.244)
Share world trade, real t-5	0.204*	-0.645	-0.716
	(0.090)	(0.516)	(0.497)
Area km2, log	0.211+	0.089	-0.092
	(0.120)	(0.143)	(0.229)
Oil exporter	-1.085	-0.709	-0.546
	(1.005)	(1.438)	(1.404)
Executive constraints, log t-5	0.040	-0.107	-0.153
	(0.084)	(0.097)	(0.110)
Rule of law	0.423**	0.259	0.228
	(0.159)	(0.217)	(0.235)
Efficiency of judiciary	0.307+	0.212	0.326+
	(0.171)	(0.188)	(0.191)
Trade with USA, t-5	-0.275+	-0.002	-0.024
	(0.144)	(0.263)	(0.248)
Trade with AUS, t-5		6.152+	5.553
		(3.631)	(3.568)
Trade with BEL, t-5		-0.544	-0.053
		(4.731)	(5.051)
Trade with NLD, t-5		6.525	6.465
		(4.643)	(4.659)
Trade with GBR, t-5		1.654*	1.751*
		(0.809)	(0.791)
Island			-0.230
			(0.804)
Km of coastline, log			0.388+
			(0.225)
Observations	864	571	528
Log-likelihood	-194.927	-154.768	-149.431

Notes: See Table G.1.

Table G.3: Additional controls (50-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 50 yrs	1.299**	1.700**	1.530**	1.820**
	(0.404)	(0.526)	(0.394)	(0.491)
Real GDPpc PPP, log t-5	0.085	-0.198	-0.012	-0.216
	(0.151)	(0.182)	(0.162)	(0.186)
Share world trade, real t-5	0.247**	0.091	0.145+	0.055
	(0.085)	(0.095)	(0.084)	(0.101)
Area km2, log	0.214*	0.256*	0.284*	0.301**
	(0.090)	(0.120)	(0.111)	(0.110)
Oil exporter	-1.024	-1.302	-0.986	-1.229
	(0.749)	(0.953)	(0.838)	(0.921)
Executive constraints, log t-5	0.031	0.042	-0.036	-0.011
	(0.071)	(0.070)	(0.078)	(0.075)
Rule of law		0.502**		0.385**
		(0.144)		(0.149)
Efficiency of judiciary			0.523**	0.355*
			(0.169)	(0.150)
Dummy 1956-1965	-3.436*	-3.458**	-3.474**	-3.590**
	(1.373)	(1.087)	(1.057)	(1.011)
Dummy 1966-1974	1.219+	1.236+	1.245+	1.304+
	(0.644)	(0.681)	(0.651)	(0.690)
Dummy 1975-1983	2.375**	2.680**	2.584**	2.806**
	(0.624)	(0.667)	(0.611)	(0.658)
Constant	-5.319**	-5.611*	-8.205**	-7.361**
	(1.694)	(2.479)	(2.499)	(2.440)
Observations	997	997	997	997
Log-likelihood	-222.590	-212.353	-214.637	-208.758

Notes: 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. All specifications include a constant and period dummies (not shown). Standard errors, computed by bootstrapping the results 1000 times, are in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Table G.4: Additional controls (50-year horizon)

	(1)	(2)	(3)
Exp. containerized trade, 50 yrs	1.664**	1.627*	1.569*
	(0.504)	(0.692)	(0.710)
Real GDPpc PPP, log t-5	-0.035	-0.051	-0.193
	(0.184)	(0.229)	(0.234)
Share world trade, real t-5	0.145	-0.815+	-0.899+
	(0.091)	(0.460)	(0.475)
Area km2, log	0.291**	0.186	-0.009
	(0.111)	(0.153)	(0.209)
Oil exporter	-0.985	-0.887	-0.789
	(0.929)	(1.318)	(1.243)
Executive constraints, log t-5	0.024	-0.105	-0.141
	(0.078)	(0.090)	(0.099)
Rule of law	0.362**	0.221	0.173
	(0.138)	(0.208)	(0.213)
Efficiency of judiciary	0.289+	0.204	0.295
	(0.148)	(0.177)	(0.188)
Trade with USA, t-5	-0.218	0.111	0.105
	(0.139)	(0.227)	(0.215)
Trade with AUS, t-5		6.134*	5.795+
		(3.063)	(3.142)
Trade with BEL, t-5		-0.349	0.150
		(5.254)	(5.393)
Trade with NLD, t-5		7.150	7.102
		(5.046)	(4.966)
Trade with GBR, t-5		1.614*	1.741*
		(0.773)	(0.808)
Island			-0.364
			(0.798)
Km of coastline, log			0.359
			(0.218)
Observations	980	579	536
Log-likelihood	-197.017	-155.630	-151.666

Notes: See Table G.3.

Table G.5: Robustness checks: sub-samples (5-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 5 yrs	1.335**	1.129*	1.249**	1.027*
	(0.380)	(0.506)	(0.415)	(0.504)
Real GDPpc PPP, log t-5	-0.086	-0.052	-0.123	0.047
	(0.168)	(0.255)	(0.176)	(0.229)
Share world trade, real t-5	0.188+	-0.847	0.272	-1.164+
	(0.112)	(0.624)	(0.188)	(0.704)
Area km2, log	0.219+	0.088	0.122	0.089
	(0.120)	(0.145)	(0.127)	(0.143)
Oil exporter	-1.521	0.101	-1.251	-0.178
	(1.763)	(2.604)	(1.313)	(1.632)
Executive constraints, log t-5	0.041	-0.099	0.009	-0.131
	(0.084)	(0.092)	(0.079)	(0.095)
Rule of law	0.437**	0.222	0.400*	0.171
	(0.163)	(0.216)	(0.187)	(0.231)
Efficiency of judiciary	0.308+	0.210	0.279+	0.144
	(0.157)	(0.185)	(0.163)	(0.195)
Trade with USA, t-5	-0.119	-0.215	-0.137	-0.076
	(0.377)	(0.553)	(0.302)	(0.340)
Trade with AUS, t-5		8.043+		9.356*
		(4.459)		(4.773)
Trade with BEL, t-5		-0.301		1.068
		(6.423)		(6.169)
Trade with NLD, t-5		8.232		6.238
		(5.373)		(5.979)
Trade with GBR, t-5		1.555*		3.084+
		(0.758)		(1.633)
Observations	839	552	696	551
Log-likelihood	-189.252	-149.735	-182.308	-144.999
Sub-sample	Excl. CAN & MEX	Excl. CAN & MEX	Excl Common-wealth	Excl Common-wealth

Notes: See Table G.1.

Table G.6: **Robustness checks: sub-samples (5-year horizon)**

	(1)	(2)	(3)	(4)
Exp. containerized trade, 5 yrs	1.264**	1.169*	1.541**	1.587**
	(0.391)	(0.514)	(0.281)	(0.399)
Real GDPpc PPP, log t-5	0.061	0.142	-0.075	-0.095
	(0.190)	(0.243)	(0.187)	(0.244)
Share world trade, real t-5	0.185+	-0.885+	0.199*	-0.750
	(0.096)	(0.510)	(0.089)	(0.539)
Area km2, log	0.074	0.041	0.215+	0.110
	(0.118)	(0.154)	(0.117)	(0.150)
Oil exporter	-1.101	-0.612		
	(1.038)	(1.442)		
Executive constraints, log t-5	0.014	-0.137	0.038	-0.098
	(0.084)	(0.098)	(0.080)	(0.096)
Rule of law	0.387*	0.276	0.515**	0.400*
	(0.161)	(0.205)	(0.138)	(0.191)
Efficiency of judiciary	0.243	0.265	0.286+	0.212
	(0.163)	(0.197)	(0.172)	(0.195)
Trade with USA, t-5	-0.230	0.044	-0.275*	0.073
	(0.175)	(0.252)	(0.137)	(0.288)
Trade with AUS, t-5		15.828*		6.275
		(7.439)		(3.914)
Trade with BEL, t-5		-0.568		-0.089
		(6.170)		(5.222)
Trade with NLD, t-5		5.934		6.594
		(4.921)		(4.888)
Trade with GBR, t-5		1.444+		1.512*
		(0.815)		(0.767)
Observations	847	560	838	551
Log-likelihood	-184.303	-145.285	-181.390	-142.782
Sub-sample	Excl NZL, CHN & JPN	Excl NZL, CHN & JPN	Excl. oil exp.	Excl. oil exp.

Notes: See Table G.1.

Table G.7: Robustness checks: sub-samples (50-year horizon)

	(1)	(2)	(3)	(4)
Exp. containerized trade, 50 yrs	1.759**	1.473+	1.792**	1.498+
	(0.541)	(0.755)	(0.632)	(0.833)
Real GDPpc PPP, log t-5	-0.045	-0.030	-0.123	0.001
	(0.179)	(0.247)	(0.188)	(0.241)
Share world trade, real t-5	0.117	-0.995	0.176	-1.220+
	(0.109)	(0.656)	(0.167)	(0.728)
Area km2, log	0.303**	0.176	0.193	0.144
	(0.113)	(0.157)	(0.132)	(0.151)
Oil exporter	-1.541	-0.610	-1.278	-0.592
	(1.827)	(2.482)	(1.160)	(1.527)
Executive constraints, log t-5	0.021	-0.101	-0.018	-0.130
	(0.082)	(0.091)	(0.086)	(0.098)
Rule of law	0.381*	0.197	0.388*	0.199
	(0.162)	(0.222)	(0.185)	(0.252)
Efficiency of judiciary	0.297+	0.203	0.293+	0.179
	(0.166)	(0.188)	(0.171)	(0.201)
Trade with USA, t-5	0.002	0.043	-0.030	0.055
	(0.375)	(0.555)	(0.249)	(0.261)
Trade with AUS, t-5		7.274+		8.523+
		(3.936)		(4.442)
Trade with BEL, t-5		-0.077		0.754
		(5.873)		(6.161)
Trade with NLD, t-5		8.452		7.636
		(5.467)		(6.025)
Trade with GBR, t-5		1.551*		2.402
		(0.782)		(1.868)
Observations	951	560	706	559
Log-likelihood	-190.841	-151.013	-181.899	-145.591
Sub-sample	Excl. CAN & MEX	Excl. CAN & MEX	Excl Common-wealth	Excl Common-wealth

Notes: See Table G.3.

Table G.8: **Robustness checks: sub-samples (50-year horizon)**

	(1)	(2)	(3)	(4)
Exp. containerized trade, 50 yrs	1.502**	1.387*	1.966**	2.131**
	(0.561)	(0.688)	(0.411)	(0.570)
Real GDPpc PPP, log t-5	0.083	0.144	-0.009	-0.022
	(0.194)	(0.236)	(0.183)	(0.240)
Share world trade, real t-5	0.137	-1.006+	0.135	-0.960+
	(0.090)	(0.592)	(0.093)	(0.502)
Area km2, log	0.178	0.160	0.314**	0.245+
	(0.119)	(0.174)	(0.105)	(0.138)
Oil exporter	-0.950	-0.746		
	(0.914)	(1.240)		
Executive constraints, log t-5	0.010	-0.121	0.014	-0.107
	(0.081)	(0.094)	(0.079)	(0.097)
Rule of law	0.318*	0.215	0.434**	0.339+
	(0.154)	(0.204)	(0.126)	(0.197)
Efficiency of judiciary	0.225	0.240	0.270+	0.201
	(0.147)	(0.198)	(0.150)	(0.191)
Trade with USA, t-5	-0.184	0.137	-0.223	0.192
	(0.134)	(0.232)	(0.147)	(0.263)
Trade with AUS, t-5		14.833+		6.443*
		(7.769)		(3.099)
Trade with BEL, t-5		-0.373		0.058
		(6.289)		(5.792)
Trade with NLD, t-5		6.523		7.450
		(4.933)		(5.121)
Trade with GBR, t-5		1.421+		1.495+
		(0.806)		(0.774)
Observations	958	567	948	557
Log-likelihood	-187.812	-147.570	-183.378	-143.024
Sub-sample	Excl NZL, CHN & JPN	Excl NZL, CHN & JPN	Excl. oil exp.	Excl. oil exp.

Notes: See Table G.3.