Ports, Technology and Inter-City Trade: The Economics and Geopolitics of Evolving Maritime Transport Networks

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Abstract

Maritime transport remains the backbone of global trade, yet the port and shipping network that carries it has been transformed by containerization and related technological advances. Drawing on newly available granular data—digitized historical shipping records, georeferenced ship movements, and shipment-level routing information—we present five stylized facts on the structure and evolution of the maritime network. Global shipping activity is highly concentrated among a changing lineup of dominant top ports even as lower-ranked ports disperse, while state-owned Chinese port terminal operators increasingly account for these global volumes, boosting overall port operations while delivering efficiency gains mostly to Chinese vessels. We use these facts to organize a synthesis of a fast-growing literature: containerization reshaped which port cities could expand, reinforced hub-and-spoke concentration that yields large but localized welfare gains, embedded ports in multimodal networks that amplify the returns to infrastructure, and generated market power, congestion, and environmental costs. Together, this evidence shows how evolving maritime technologies simultaneously deepen global integration and heighten the economic and geopolitical importance of critical nodes in the transport network—and of who controls them.

Keywords: transport networks, ports, international trade, trade costs, containerization, geoeconomics

JEL Classification: F13, F14, R41, R42

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1 Introduction

Ports have long been recognized as gateways to global trade, offering firms low-cost connections to international markets while generating significant local economic benefits. Alexander the Great founded the city of Alexandria to link inland river transport on the Nile with the Mediterranean Sea, transforming it into a major grain-exporting hub and, in subsequent centuries, a cultural and intellectual center of the ancient world (Cartledge, 2011).[1] But the forces shaping ports have never been purely economic: geopolitical considerations have always been present. The British East India Company established the "free port" of Singapore to secure control over the critical trade chokepoint of the Straits of Malacca (Borschberg and Khoo, 2018).[2]

While recent decades have witnessed a remarkable increase in the value of goods traded across the globe, at first glance, little seems to have changed in *how* the world moves its goods: they are still loaded onto ships at ports and carried across the seas, the same basic process that has linked economies for millennia. The sea remains the backbone of global trade, carrying around 80 percent of world merchandise trade by volume (UNCTAD, 2024). Yet this apparent continuity masks profound technological change. Successive innovations—from steamships to containerization—have revolutionized maritime transport, reducing trade costs and expanding trade flows (Hummels, 2007; Bernhofen, El-Sahli and Kneller, 2016; Pascali, 2017; Coşar and Demir, 2018).

By contrast, the economic development of *ports* and their host *cities*, and how they have adapted to shifts in maritime trading technologies, long received surprisingly little attention from economists—not for lack of interest, but because the necessary data did not exist. How did the global port network absorb the large increase in shipping volumes since the Second World War? How did ports manage the transition from bulk cargo to containerized shipping? What were the economic consequences of these changes for the trade network and for the cities and regions that host ports? To understand the economic and geopolitical effects of improvements in maritime transport technology, we should first understand how these improvements reshaped the trading network itself.

In recent years, a proliferation of granular data on trade and other measures of eco-

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[1] A hub is a central node within the trade network where trade flows are concentrated and redistributed.

[2] We use the term chokepoint to refer to a strategically critical passage with limited alternative routes.

nomic activity *at the port level* has spurred a new wave of research that incorporates more realistic features of the maritime trading network. These novel data include newly digitized modern and historical records on port activity, contemporary georeferenced data on ship movements, and detailed information on the routes commodities take from origin to destination. The main aim of this article is to provide a synthesis of this rapidly growing literature. As this literature is recent, the number of articles that have already reviewed it is limited. Faure and Ducruet (2025) provide an excellent summary of research on maritime shipping networks from a geography perspective, while Ardelean et al. (2022) document an array of novel economic facts on maritime transportation. Relative to these articles, our primary focus is on how recent improvements in maritime shipping technologies have changed not only trade flows and costs, but also the distribution of economic activity across cities and countries, as well as the geopolitical implications of these changes.

Three main conclusions emerge from this new body of work. The first is that new maritime technologies do not affect all places alike. Containerization altered the input requirements of port activity so that well-positioned cities can capture the new traffic and transition into important commercial hubs that support the broader trade network. Concurrently, others bore the cost of accommodating these technologies, with port expansion competing against alternative uses of scarce local resources. The second is that concentrating activity at a few dominant ports is double-edged: the same forces that lower costs, widen market access for even small trading nations, and increase the payoff to investment in connecting infrastructure also introduce market power, congestion, local pollution, and exposure when a critical node fails. The third is that control of these nodes has become a question of geopolitics as much as economics. As ownership of port infrastructure has shifted toward states—China above all—it has raised the prospect that ports may also serve military ends, deepen one country's reliance on another, and confer leverage over the narrow passages through which much of world trade must flow, most sharply where that reliance is asymmetric.

In the next section, we provide a set of stylized facts on the spatial distribution of maritime activity which help organize the remainder of the review.

2 Stylized Facts

This section presents five stylized facts that illustrate what the granular data described in the introduction reveal about the structure and evolution of the maritime trade network. The first three concern the spatial distribution of shipping activity: its concentration, well documented in earlier work but measured here consistently across six decades, and the changing lineup of which ports dominate. The last two shift attention from ports to their operators: state-owned firms, particularly Chinese ones, account for a large and growing share of global container throughput, and Chinese port ownership raises port scale broadly while improving efficiency primarily for Chinese vessels. Together, these facts organize the remainder of the review.

Stylized Fact 1. *Global shipping activity is highly concentrated: a small number of ports account for a disproportionate share of world shipping.*

Figure 1 plots the cumulative share of world shipping activity by port. It shows that maritime trading infrastructure is very unevenly distributed across space, with a handful of ports accounting for a disproportionate share of world shipping. This feature of the data is evident in both 1951 and 2008 (blue and red respectively): at both points in time, the five largest ports in the world accounted for about 20% of world shipping as measured by the number of ship calls at the port. The existing literature has documented this uneven distribution of shipping activity and has linked it to the fact that the shipping network has a strong hub-and-spoke structure (Ducruet, Cuyala and El Hosni, 2018; Faure and Ducruet, 2025). An implication of this network configuration is that most trade is indirect: goods rarely move directly from origin to destination and the typical cargo is likely handled by a hub, as also established empirically by Ganapati, Wong and Ziv (2024). This large concentration of shipping activity in a few hubs suggests the presence of scale economies in maritime transportation, consistent with the micro-level evidence documented in Ardelean et al. (2022); we examine these scale economies and their consequences for trade and the spatial distribution of economic activity in Section 4. At the same time, concentration makes the hubs potential bottlenecks—nodes within the network with no easy substitutes—a vulnerability we return to when discussing congestion (Section 5) and geopolitical control (Section 7).

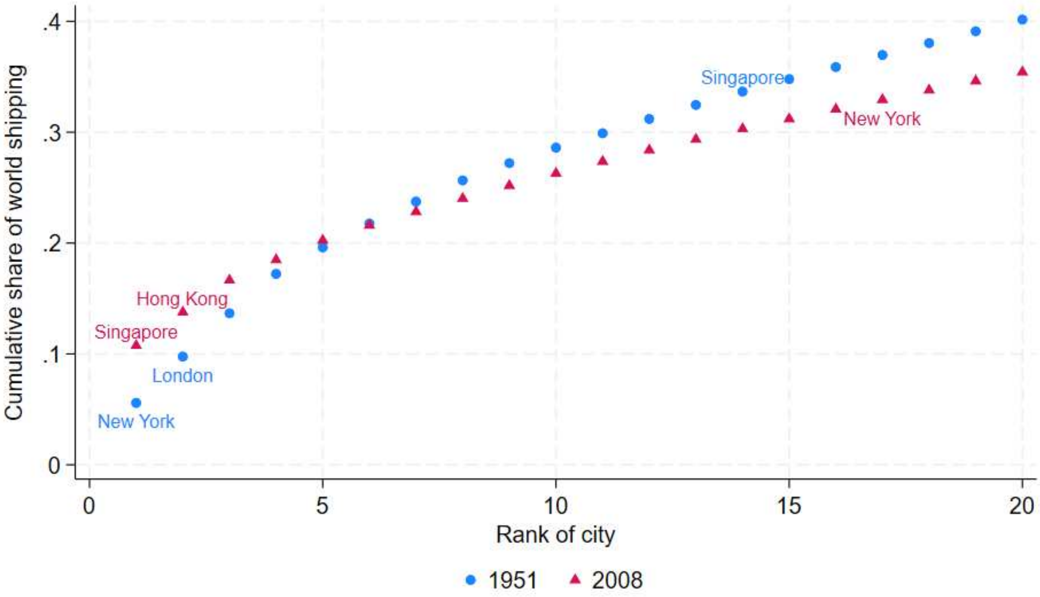

Figure 1: Cumulative distribution of port city shares in number of ships, 1951 and 2008
Notes: Source: Lloyd's Shipping Index (See Appendix A for details on the dataset.) ■

Stylized Fact 2. *Concentration at the top of the port distribution has intensified over time, while shipping activity among lower-ranked ports has become more dispersed.*

This concentrated structure has not been static. At the top of the port distribution, port activity has become even more concentrated over time, as evidenced by Figure 1. One important technological change between 1951 and 2008 is the advent of containerization in the 1950s and 1960s, which marked a pivotal breakthrough in maritime technology (Levinson, 2016). By standardizing cargo into easily transferable units, containers cut loading times by up to 90-95% (Kahveci, 1999; Port of San Francisco, 1971). In addition, containerization facilitated intermodal transport across ships, trucks, and trains (Bernhofen, El-Sahli and Kneller, 2016; Fuchs and Wong, 2026). These efficiencies slashed shipping costs and revolutionized supply chains, enabling the rise of global production networks and just-in-time manufacturing (Ganapati and Wong, 2023). As a result, container ports have increasingly become critical nodes in global trade, leading to the increased spatial concentration of maritime activity in a few key entrepôts—trading hubs where goods are shipped through, from other origins and bound for other destinations (Ganapati, Wong and Ziv, 2024). In other words, the scale economies that have always been inherent to maritime transportation have been further reinforced by new maritime technologies. Consistent with this, Ardelean et al. (2022) document substantial increases in scale economies at the ship level.

At the same time, the cumulative distribution has also flattened out for lower-ranked ports (right tail of Figure 1), suggestive of potential offsetting costs to concentrating port activity. Indeed, several scarce inputs are necessary to conduct shipping activity, including geographic inputs such as deep ports and abundant land, as well as labor. As containerized trade uses some of these inputs—most notably, port depth (Brooks, Gendron-Carrier and Rua, 2021) and land (Ducruet et al., 2024*b*)—more intensively, it can drive up the cost of scarce local inputs and thus disperse port activity outside the main hubs. We discuss the changing input requirements of containerization and the local costs they impose on port cities in more detail in Section 3. Beyond input costs, the new network structure has also led to additional costs arising from inefficiencies such as market power, congestion, and adverse environmental effects, which we examine in Section 5.[3]

Stylized Fact 3. *The identity of the world's largest ports has changed substantially over time.*

There has been substantial churn in terms of which ports stand at the top of the distribution. The biggest ports in the 1950s, New York and London, have been displaced by port cities such as Singapore and Hong Kong (and most recently, Chinese ports such as Shanghai), which were far more peripheral in the 1950s (Levinson, 2016). As we discuss in Section 3, this churn reflects the changing input requirements of containerization: many historically dominant ports lacked the natural depth and available land that the new technology demands. The churn at the top of the port distribution has been accompanied by changes not only in *where* the largest ports are located, but also in *who* owns and operates them.

Stylized Fact 4. *Among the world's largest container terminal operators, state-owned companies account for a substantial and growing share of global throughput, driven in particular by the rapid expansion of Chinese state-owned firms.*

Figure 2 shows that the seven largest ports worldwide in 2024 together account for almost 40% of global container throughput. Among these seven ports, four of them

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[3] An interesting question is to what extent the changing concentration of port activity has driven, and has been driven by, the changing concentration of cross-country trade. We leave this question for future research.

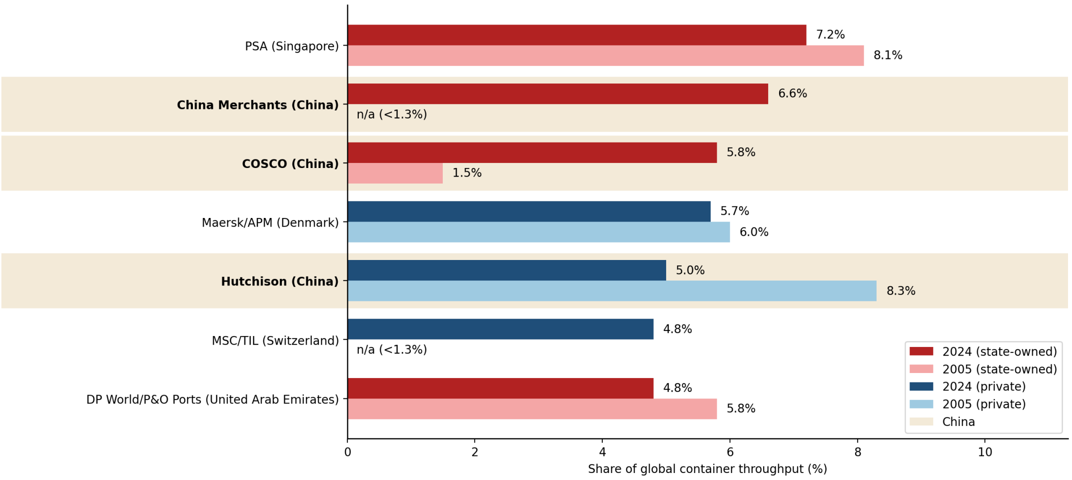

Figure 2: Top 7 Global Container Terminal Operators in 2024

Notes: China Merchants and MSC were not listed in the top 10 global terminal operators in 2005, implying that their shares were less than 1.3%. Sources are Drewry's Global Container Terminal Operators Annual Review and Forecast 2025/26; Drewry Shipping Consultants, Annual Review of Global Terminal Operators, 2006. ■

are state-owned: PSA (by Singapore), China Merchants and COSCO (by China), and DP World/P&O Ports (by the United Arab Emirates). The state-owned ports account together for 24.4% of global container throughput. The increased prevalence of state-ownership is particularly driven by China: When China's Belt and Road Initiative (OBOR) took off in the early 2010s, China's two state-owned companies COSCO and China Merchants expanded rapidly, currently ranking as the second- and third-largest container terminal operators in the world, with a combined market share of 12.4% in 2024 (up from <3% in 2005).

Stylized Fact 5. *Chinese public port ownership increases port scale for both Chinese and non-Chinese carriers, but efficiency gains accrue primarily to Chinese vessels.*

Port ownership may matter not just for the scale of port operations but also for how efficiently different ships are served. Zooming into the increase in Chinese public port ownership, we document its effects on port scale and efficiency using newly assembled data, combining port call data from *Global Fishing Watch* with Chinese global port ownership data from Banach and Gunter (2024) and ship operator information from EconDB.[4]

Figure 3a shows that China's public port ownership substantially increases the scale of foreign port operations. Port calls from COSCO ships almost quadruple by year 3

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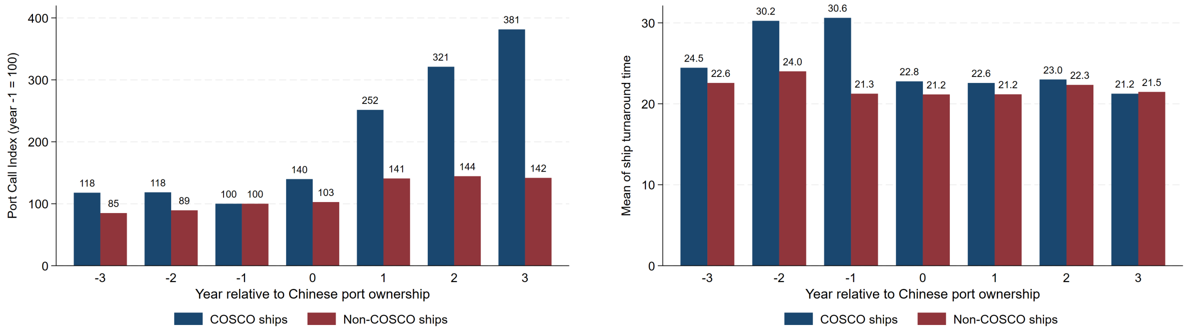
[4] See Appendix B for details on the dataset.



(a) Port calls

(b) Ship turnaround times

Figure 3: Port calls and ship turnaround times before and after Chinese ownership, by shipping company

Notes: Mean port calls in the year before Chinese port ownership: 11.5 (COSCO ships), 301.6 (non-COSCO ships). Sources are described in Appendix B. ■

after Chinese port ownership. Port calls from non-COSCO ships also increase, though by a smaller margin—about 40%—from a much higher initial level. Taken together, Chinese ownership increases total port calls by about 50%. These patterns are consistent with causal evidence for Piraeus showing increased COSCO ship handling after Chinese control (Koenig et al., 2024), with higher throughput at European ports after Chinese ownership (Kalkschmied and Stricker, 2025), and with a reorientation of European inland trade corridors toward OBOR-aligned routes following Chinese port acquisitions (Nikalexi, 2025).

Chinese port ownership has often coincided with higher port investment, which can improve efficiency. Gains in operational efficiency may disproportionately benefit Chinese ships, either because they receive preferential treatment or because investments occur at terminals primarily used by Chinese carriers. At the same time, efficiency improvements can benefit other ships and help ports attract additional traffic (potentially creating dependence on a specific port and route, as discussed in the previous section). To obtain a proxy for efficiency, we compute ship turnaround times before and after Chinese takeover. Figure 3b shows that turnaround times fall for COSCO ships but do not change for non-COSCO ships. Because COSCO ships started with longer turnaround times, this convergence could reflect efficiency improvements at COSCO-serving terminals or differential priority for COSCO vessels.

A key conclusion that emerges from these five stylized facts is that the *structure* of the maritime network matters a great deal for economic and geopolitical outcomes. Scale economies in shipping pull activity toward a few global hubs, while rising local costs—land intensity, congestion, and environmental damage—push it outward, and together these opposing forces reshape both the distribution and the identity of the world's leading ports. Port ownership, in turn, gives states a lever over this structure, from maritime chokepoints to economic leverage over other countries. Understanding the consequences of maritime transport technologies therefore requires weighing global network efficiencies against local constraints—the task of the remainder of this review.

In the following sections, we discuss how recent research, leveraging the types of new data we have showcased here, has uncovered the economic and geopolitical mechanisms driving these stylized facts and traced out their effects on local and regional economies. We proceed from the local to the global: we begin with the local forces underlying the dispersion and churn documented in Stylized Facts 2 and 3, before turning to the network-wide consequences of the scale economies behind the concentration in Stylized Fact 1. Section 3 examines the local benefits and costs of containerization for port cities; Section 4 turns to the network it created, where scale economies concentrate trade in a few hubs; and Section 5 considers the inefficiencies—market power, congestion, and environmental costs—that this network structure entails. Because containerization allowed cargo to move seamlessly across ships, rail, and trucks, ports are now embedded in larger multimodal transport networks, whose economic implications we examine in Section 6. Finally, Section 7 moves beyond economic benefits and costs: motivated by Stylized Facts 4 and 5, we discuss three mechanisms through which China can use port control to pursue geopolitical objectives—military dual-use of ports, the creation of economic dependence for leverage, and control over maritime chokepoints during disruptions.

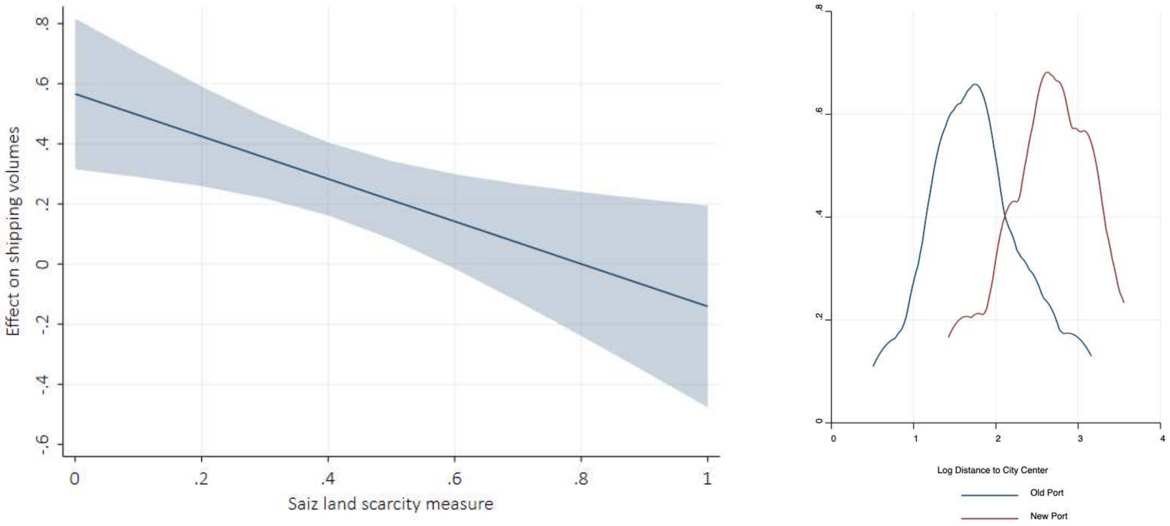
3 The Local Benefits and Costs of Containerization

The relationship between transport technology and trade has long been central to economic growth and development (Hummels, 2007; Ganapati and Wong, 2023). However, while researchers traditionally examined how technologies reduce the friction of distance in general, recent research highlights that the effects of new technologies such as containerization go far beyond transport cost reductions. For containerization, new research has found that existing port cities were differently suited to adopting the new technology, leading to heterogeneous local economic effects as a result of a changing maritime network.

Research has found that containerization was relatively quickly adopted and increased trade flows substantially. Leveraging detailed data at the port level, Rua (2014) finds that 90 percent of countries adopted container-handling technology at their ports by 1983, less than three decades after it was first introduced in 1956. Multiple studies find that the adoption of the new technology increased trade flows, consistent with the standard mechanism that reduced trading costs increase trading volume. Exploiting cross-country variation in the adoption of container facilities, Bernhofen, El-Sahli and Kneller (2016) estimate that containerization increased trade ninefold across adopting countries, implying that containerization accounts for a significant portion of global trade growth in recent decades. According to estimates by Coşar and Demir (2018), U.S. maritime exports would be 21 percent lower in the absence of containerization.

While this research suggests that containerization reduced trade costs, perhaps substantially so, and was almost uniformly adopted, different port cities were differentially impacted. The reason for this is that containerization substantially changed the input mix necessary to conduct shipping activities. First, faster turnaround times in ports encouraged demand for the construction of larger ships. As larger ships sit deeper in the water, containerization shifted port activity towards cities with greater *natural port depth*, where costly dredging was not necessary. Natural port depth has been shown to be a good predictor of which U.S. port cities adopted container technology, and using this exogenous variation, Brooks, Gendron-Carrier and Rua (2021) find that containerization had positive local economic benefits: population in counties near containerized ports grew twice as much as in other coastal counties between 1950 and 2020. A similar identification strategy can be used to show that trade has a positive effect on GDP per capita, both in levels and in growth terms (Altomonte, Colantone and Bonacorsi, 2018). Therefore, geographic endowments may go some way towards explaining the churn documented in Figure 1. Many historically important ports simply do not have the necessary natural depth to achieve the status of a global hub in the era of containerized cargo-handling.

Second, since container handling is conducive to automation, demand for port *labor*, particularly longshoremen, decreased dramatically. Evidence has been provided for this in the case of U.S. ports (Gomtsyan, 2016). Surprisingly, unemployment in U.S. port cities decreased with containerization. This suggests that increased port activity



(a) Effect of containerization on shipping by land scarcity (b) Port moves within cities

Figure 4: Evidence on the land costs of containerization

Notes: Replicated from Figure 1 and Figure F.2 in Ducruet et al. (2024*b*). Panel (a) displays the estimated effect of natural port depth, which captures a port city's ability to containerize, on shipping flows by the port city's land scarcity from a specification in which port depth is interacted with a canonical measure of land scarcity. Panel (b) shows the kernel density of ports' log distance from the city center in 1953 (blue) and 2017 (red), for the set of port cities in which a new port was established after 1953. Source: Ducruet et al. (2024*b*). ■

brought about enough economic opportunities to more than offset the negative direct effect. Adding further nuance to the picture, total labor costs did not decrease immediately after containerization (Bridgman, 2024), as organized port workers were able to negotiate compensation deals, and thus extract rents, after the advent of the new technology.

Third, containerization massively increased the amount of *land* used by ports and by complementary transport infrastructure such as road and rail connections (Bernhofen, El-Sahli and Kneller, 2016). The key reason for the greater land intensity of container ports is that faster turnaround times can only be achieved at the expense of building larger terminals. As Corbett (2010, p. 164) writes: "Rows of finger piers adjacent to a densely built up city could not adequately serve container shipping, which involved larger ships that required larger wharves and much larger areas of open space for loading and unloading." Put differently, containerization induced a *cost–space trade-off* (Ducruet et al., 2024*b*). In fact, Rodrigue (2016, p. 118) names site constraints as the primary challenge associated with containerization.[5]

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[5] While land reclamation has been used to expand into the sea, it is typically a very costly investment, which likely explains why it has not been done extensively outside Asia (Martín-Antón et al., 2020).

The general equilibrium implications of the increased land use associated with containerization have been explored in Ducruet et al. (2024*b*). They develop a theory in which port development, conducted by atomistic landlords in port cities, reduces transshipment costs but requires local land as an input. As a result, more port development is conducted where land prices are low. Two pieces of empirical evidence support this theoretical prediction. First, containerization led to more port expansion in cities where land was less scarce (Figure 4a). Second, within cities ports have relocated towards the outskirts of cities, where land prices are typically lower (Figure 4b). Importantly, in contrast to the research discussed above which found reduced form evidence consistent with positive local economic effects of containerization, this mechanism suggests an important mitigating local cost of containerization: the potential to crowd out economic activity due to its land-intensive nature. More generally, this mechanism has the potential to rationalize the post-containerization reallocation of port activity away from the largest cities (Figure 1), since these are the cities where land tends to be the most expensive. In addition, this mechanism also has the potential to shed light on the dispersion of shipping activity witnessed for smaller ports. If containerization entails significant local costs, outside of hubs, the stronger incentive may be to restrict port expansion beyond a certain scale. Indeed, in reduced form work, Ducruet et al. (2024*b*) find that cities with larger increases in shipping had no discernible population response.[6]

4 Economies of Scale and Its Consequences

More broadly, advances in shipbuilding technology—including the construction of megaships—have further pushed the boundaries of economies of scale in maritime transport. Over time, their size has increased dramatically, allowing for greater efficiency and lower per-unit shipping costs. The average size of newly built container vessels increased by 4 times between 1960 and 1990 (Ducruet et al., 2024*b*). The largest containership globally in 2025 (the MSC Irina) is the length of four football fields and could carry 24,346 containers—more than 30 times the capacity of the earliest containerships (The Maritime Executive, 2023). By merging global AIS containership port-call data with shipment-level customs transactions, the movement of goods that are transported can be traced

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[6] While these results are different to those in Brooks, Gendron-Carrier and Rua (2021), they are not directly comparable as Ducruet et al. (2024*b*) use a sample of cities from around the world, while Brooks, Gendron-Carrier and Rua (2021) study U.S. counties.

from origin to destination, revealing that approximately 80 percent of trade is shipped indirectly (Ganapati, Wong and Ziv, 2024). The median shipment stops at two additional countries before reaching its final destination. Moreover, this indirect routing is highly concentrated: over 90 percent of such trade is channeled through a small number of strategic entrepôts—including Singapore, the Suez Canal (Egypt), and the Netherlands—establishing that the trade network is a hub-and-spoke system.[7]

The hub-and-spoke structure in container shipping has important trade and economic implications. First, because containerships operate on fixed round-trip routes, freight rates on the outbound and return legs are negatively correlated which inextricably links a country's imports and exports with trading partners on the same route—the *round-trip effect* (Wong, 2022).[8] On routes with unbalanced trade flows, transport faces the additional challenge of trying to utilize the excess transport capacity on the lower demand journey, commonly known as the "backhaul problem" in the transportation literature. This imbalance can influence the location of economic activity, especially under agglomeration forces (Behrens and Picard, 2011), and may lead to unintended consequences—such as reduced capacity for trade in the opposite direction—when trade policy restrictions like import tariffs are imposed (Ishikawa and Tarui, 2018; Hayakawa, Ishikawa and Tarui, 2020; Wong, 2022). Transport firms also have to further optimize transport capacity by repositioning empty containers, which reinforces the logistical interdependence between countries along shipping routes (Economides, 2024).

Second, since larger ships have lower per-container costs, smaller countries can benefit from scale economies in shipping by utilizing the hub-and-spoke trade networks. Figure 5, replicated from Ganapati, Wong and Ziv (2024), illustrates how routing through entrepôt hubs can generate market access for smaller countries by allowing them to access larger vessels. The figure plots the average ship size coming from each country against their U.S.-bound traffic volume, with two circles per country—one for direct shipments to the U.S. and one for shipments routed via entrepôts. As expected, larger trading countries tend

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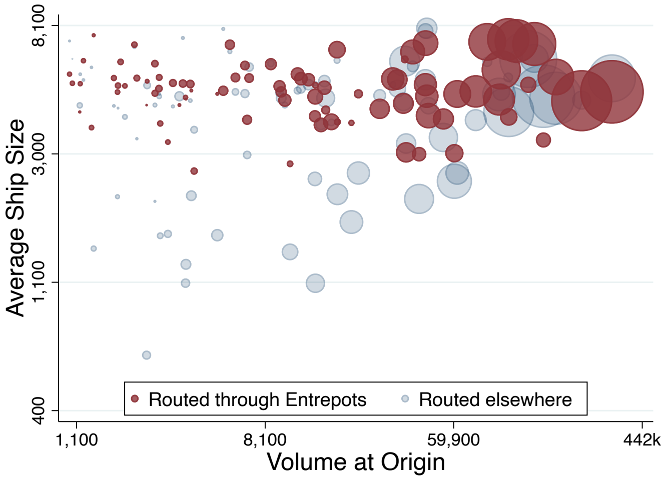
[7] Focusing on the hubs within the network, Do et al. (2025) study the economic returns to being a hub country and show that transshipment not only increases a hub country's imports of the same product, but also boosts its exports of downstream goods—highlighting broader supply chain benefits.

[8] The *round-trip effect* refers to a phenomenon in the transportation sector where a shock to the quantity of shipments from locations i to j subsequently affects the transport price in the opposite direction—from j back to i (Wong, 2022). This arises because round-trip routes by transport firms link the supply of transport services within routes, so changes in demand on one leg influence pricing on the return leg. This phenomenon is not unique to just container shipping but also applies to air, freight, and rail transport.

Figure 5: Link Between Indirect Trade and Ship Size



Notes: Replicated from Figure 10 in Ganapati, Wong and Ziv (2024). The x-axis shows the total export volume in TEUs from an origin country to the United States. The y-axis shows the average ship size which arrives from an origin country to the United States. Each country is represented by two data points, a blue and a red circle. The red circle indicates the corresponding information for trade from an origin that is routed through an entrepôt while the blue circle is for trade that is not. Circle size denotes shipping volume specific to the route (either through an entrepôt or not). Note that trade that is not routed through an entrepôt (blue circle) could either be shipped directly to the United States or shipped via a non-entrepôt. Source: Merged global AIS containership port-call data with U.S. shipment-level customs transactions, Ganapati, Wong and Ziv (2024). ■

to use similarly large-sized vessels regardless of routing (right side of Figure 5). However, smaller countries that route their shipments through entrepôts also access similarly large ships, effectively closing the "ship-size gap" relative to large countries (red circles on the left side of Figure 5, compared to blue circles for direct shipments).[9] For shipments with the same origin, U.S. destination, and controlling for the total number of stops, those routed through entrepôts arrive on ships that are on average 15 percent larger (Ganapati, Wong and Ziv, 2024). In this way, the hub-and-spoke trade network enables smaller countries to benefit from the scale economies in shipping that they could not achieve alone, improving both their market access and competitiveness in global trade.

Third, local changes within hub-and-spoke trade networks can have far-reaching effects. For instance, the 2016 Panama Canal expansion increased trade by 11 percent between country pairs using the canal, while it also led to widespread global benefits due to the interconnected structure of shipping networks (Heiland et al., 2025). In a quantification of the impact of the hub-and-spoke trade network on global trade and welfare, Ganapati, Wong and Ziv (2024) show that infrastructure investments yield welfare

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[9] This network structure can mitigate the transport cost penalties that typically burden smaller, geographically disadvantaged, or infrastructure-poor countries (Limao and Venables, 2001).

gains that are on average 10 times higher at entrepôts than non-entrepôts. Moreover, these benefits are highly localized: decaying at five times the rate when measured by their spillover effects—via the trade network—on neighboring countries. Scale economies further concentrate and magnify these gains locally at and around entrepôts, highlighting that scale economies in transportation can act as a source of agglomeration. A similar dynamic appears in bulk shipping, where carriers often search for new cargo after delivery, thereby creating network effects between neighboring countries (Brancaccio, Kalouptsidi and Papageorgiou, 2020).

5 Inefficiencies Associated with Ports

Beyond their role in concentrating activity around key hubs, scale economies also create scope for price discrimination across routes, contribute to congestion at ports, and intensify the environmental burdens faced by port cities. We briefly summarize the growing literature that examines each of these margins and the policies that might mitigate their effects.

Trade routes involving larger countries tend to have higher volumes and involve more carriers, while smaller developing countries—often positioned as spokes within the network—face limited access to carriers and higher transportation costs (Hummels, Lugovskyy and Skiba, 2009). Subsequent work on price discrimination and market power has focused on average shipper size (Asturias, 2020), the sizes and types of firms demanding shipping services (Ignatenko, 2025; Ignatenko et al., 2025), informational frictions and search (Ardelean and Lugovskyy, 2023), as well as the strategic interactions between carriers and firms (Cristoforoni et al., 2025).

As bottlenecks in the shipping network, ports are also particularly prone to congestion. Since ships need to queue at ports in order to get loaded and unloaded, even small demand shocks can make the queue escalate sharply (Brancaccio, Kalouptsidi and Papageorgiou, 2025), leading to convex costs of congestion. These congestion costs account for a non-negligible part of overall shipping costs (Abe and Wilson, 2009). Other shocks to ports, such as extreme weather events, can exacerbate these issues by redirecting traffic to other ports and creating congestion there (Massoni, 2025). It is only recently that traffic congestion has started receiving more attention in quantitative general equilibrium evaluations of the effects of transport infrastructure (Allen and Arkolakis, 2022; Redding and Turner, 2015; Fuchs and Wong, 2026).

Finally, port activity often entails severe environmental consequences. Among other things, shipping can induce air and water pollution as well as noise (Sakib, Gissi and Backer, 2021),[10] and 60 to 90% of maritime emissions occur while ships berth at the port (Zheng, Zhao and Shao, 2020). Bulk traffic is a particularly heavy emitter of particulate matter (PM), linked to tens of thousands of deaths annually (Corbett et al., 2007), while container shipping causes pollution primarily through congestion in its complementary road infrastructure (Ducruet et al., 2024*a*). Ozone emissions are also substantial (Moretti and Neidell, 2011). Port regions of the world also emit significantly more greenhouse gas than non-port regions, and such emissions are correlated with lower life expectancy and higher mortality rates (Ducruet et al., 2024*a*). Surprisingly, port regions have less PM emissions than inland regions – this is likely due to local wind dispersion in coastal areas. Port regions with higher population density, however, feature higher concentrations of both GHG and PM.

To what extent can policy alleviate the environmental costs of port activity and shipping? Economides (2025) shows that the global emissions of containership voyages servicing Los Angeles and Long Beach declined by 10% following the introduction of a new queuing system. Exploiting the introduction of Emission Control Areas in the U.S., it has also been shown that counties near heavy ship traffic saw a 4% decline in PM, a 1.7% reduction in low birth rate, and a 2.8% reduction in infant mortality due to the policy (Hansen-Lewis and Marcus, 2025). That said, the positive effects of regulation are mitigated through ship re-routing, substitution toward on-land emissions, and individuals' increased time spent outdoors. Moreover, policy needs to account for leakage through mode substitution. Lugovskyy, Skiba and Terner (2025) estimate that, perversely, the International Maritime Organization's 2023 regulation (IMO2023) capping CO2 emissions from global maritime shipping will *increase* total transport-related carbon emissions in both the short and the long run, as demand substitutes toward air (and land) transport—with air freight up to two orders of magnitude more carbon-intensive than

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[10] One well-studied aspect is the effect of transportation on greenhouse gas (GHG) emissions. International freight transport is responsible for one third of trade-related GHG emissions (Cristea et al., 2013), although the gains from trade exceed these environmental costs (Shapiro, 2016). Estimating the impact of a unilateral carbon tax policy on ships by the EU, Ludwig (2025) finds that EU carbon taxes can significantly reduce maritime emissions if transport supply is elastic but the resulting trade decline leads to an overall welfare loss. For a more detailed account of the GHG emissions linked to transportation, see Copeland, Shapiro and Taylor (2021).

containerized shipping. These results cast light on the complexity of designing policies that target environmental externalities in port cities.

6 Multimodal Transport

Modern trade often moves through multimodal transport networks, raising the question of how their structure shapes welfare and where their vulnerabilities lie. Containerization reduced the cost of transshipment, the transfer of cargo between vessels or transport modes en route to its final destination, by allowing standardized containers to move seamlessly across ships, rail, and trucks without unpacking (Levinson, 2016, p. 10). This decline in transshipment costs was central to the rise of multimodal transport networks: a container of goods from Asia can now move from a West Coast port onto rail and trucks bound for interior markets without ever being unpacked.

Central to identifying the importance of these multimodal transport networks are the ways different modes of transportation interact. When one part of the network is improved, for example by upgrading a major highway, two competing forces arise. First, there is a substitution effect: because the highway is now relatively cheaper, some traffic on rail or ships will be diverted onto trucks instead.[11] Second, there is a general equilibrium complementarity effect: because the upgraded highway makes it easier and cheaper for the connected locations to buy and sell goods, it improves their market access which increases overall trade and can ultimately increase traffic across all modes of transport. Which of these effects dominates, or what the net effect ultimately is, depends on the topography of the network and where these transport modes are situated within it.

Recent quantitative work shows that accounting for the fact that much of trade

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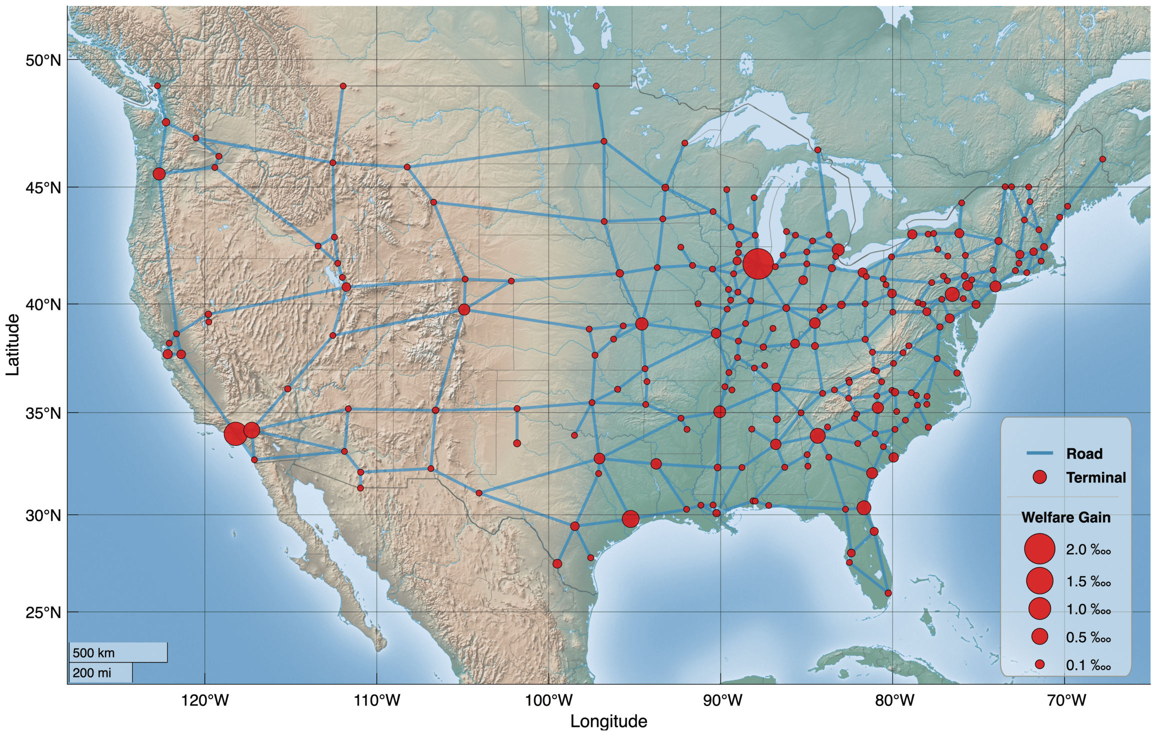
[11] Most of the economics literature on the elasticity of substitution between transport modes has focused on the substitution between ocean and air transport (Harrigan, 2010; Hummels and Schaur, 2013; Lugovskyy, Skiba and Terner, 2025; Tolva, 2025), or within maritime transport itself, such as the choice between bulk and containerized shipping (Coşar and Demir, 2018). Rather than directly estimating substitution elasticities, some of this work infers substitution patterns from differences in costs and shipment characteristics. Reported elasticities along the air–ocean margin tend to be relatively large: Hummels and Schaur (2013) estimate values between 2.7 and 6.5, Lugovskyy, Skiba and Terner (2025) report an IV estimate of 10.3, while Tolva (2025) finds an estimate of 2.6 using the closure of Russian airspace as a quasi-natural experiment. Using shipment-level variation, Harrigan (2010) shows that a 1 percent increase in value per weight raises the probability of air shipment by 0.2 percentage points. On the elasticity of substitution between rail and truck, Fuchs and Wong (2026) estimate a value of 1.10. Turning to the rail–sea margin, Mau, Xu and Zheng (2025) estimates a substitution elasticity of 1.957 for a single-sector version of their model and finds that transport mode choice for exporters is more rigid than the choice across different ports.

is multimodal matters. Evaluating infrastructure improvements without multimodal flexibility—effectively collapsing the network to a single mode (roads)—leads to lower average welfare effects by 22.2% compared to the full multimodal network (Fuchs and Wong, 2026). In their setting, the complementarity in interactions between transport modes dominates the substitution channel, implying that a unimodal approach underestimates total gains because it fails to account for market access benefits, particularly for central links within the network. Complementarities across transport modes are also reflected in how different infrastructure investments shape spatial outcomes: Bonadio (2021) shows that improvements in Indian ports and roads generate distinct distributional effects, with port upgrades benefiting export-oriented coastal regions and road investments favoring domestically-oriented ones, while coordinated investments between ports and roads yield larger gains overall. By contrast, when assessing the impact of removing China's 100 busiest highway segments, Fan, Lu and Luo (2019) show that failing to account for traffic rerouting and the substitution between highways and domestic roads can overestimate the welfare losses by 21%, highlighting that highways and domestic roads are substitutes for one another. Similarly, Tolva (2025) finds that allowing for endogenous mode substitution reduces counterfactual welfare losses from the closures of Russian airspace and the Suez Canal, as shipments can be reallocated towards unaffected modes.

At the heart of the rise of multimodal transport networks are the intermodal terminals themselves, key locations where cargo switches between transport modes—like ports. Precisely because these terminals are where modes connect, lowering their transshipment costs can yield large returns. Fuchs and Wong (2026) find that improving both ports and inland terminals could generate \$0.46-3.85 billion in additional real GDP within a multimodal transport network, with these benefits being 2.7 times higher on average without congestion. Figure 6, replicated from Fuchs and Wong (2026), visualizes the intermodal terminals that generate these large welfare gains. As expected, some of the largest welfare impacts are concentrated in major coastal hubs such as Los Angeles (including Long Beach) and Houston. However, several highly influential terminals are located in the interior of the country—Chicago, Atlanta, and Kansas City in particular—underscoring the importance of inland multimodal connections that move goods between coastal ports

Figure 6: Welfare Benefits of Improving Intermodal Terminal



Notes: Replicated from Figure 8, Fuchs and Wong (2026). This figure visualizes the the welfare impact of lowering the transshipment cost in each intermodal terminal node by 1 percent. The network includes 228 nodes in total, each corresponding to a separate counterfactual. The red circle size is proportional to the magnitude of welfare gains, with larger circles indicating larger welfare effects. The blue lines indicate the graph representation of the primary road network. State boundaries are included. See Table 3 Fuchs and Wong (2026) for details on the top 10 list of intermodal terminals with the highest welfare impacts. Source: Fuchs and Wong (2026)

and domestic markets.[12] Chicago stands out as the most impactful terminal, reflecting its central role as the nation's primary intermodal hub linking the Midwest to both coasts.

Hubs can become chokepoints when disruptions occur within the transport network.[13] While the utilization and concentration of traffic at these hubs—whether globally like Singapore and the Suez Canal or locally like Chicago in the U.S.—may appear to increase the fragility of supply chains, this concentration is also the result of global trade and supply chains taking advantage of the efficient, cheap, and reliable transport technology.The trade-offs between efficiency and resilience are thus inherent to the spatial organization of trade. One natural policy response may be to increase capacity at ports through in-

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[12] While this special issue focuses primarily on maritime transport, railroads play an equally critical role in these inland connections, having dramatically lowered transport costs and linked remote regions to global markets. Across diverse settings—including the U.S. (Donaldson and Hornbeck, 2016; Hornbeck and Rotemberg, 2024), India (Donaldson, 2018), and sub-Saharan Africa (Jedwab and Moradi, 2016)—rail access has been shown to boost trade, population growth, and long-run development, especially in previously isolated areas. Accounting for transport network quality is also important, as Ma and Tang (2024) show that variations in road and railroad quality across time and space in China can significantly bias the estimated distributional impacts of transportation networks.

[13] The pandemic has highlighted the fragility of these nodes, with persistent supply chain disruptions caused by port congestion and container shortages (Steinbach, 2022).

vestment. Focusing on bulk shipping and the port network only, Brancaccio, Kalouptsidi and Papageorgiou (2025) evaluate the returns to infrastructure investment at ports in the presence of disruptions and congestion. They find that, net of costs, investment is worthwhile at only a handful of US ports. Investment seems to be particularly valuable where spillovers are large, in the sense that investment at one port decongests many others.

A more drastic response would be to step back from these networks altogether. But reshoring production and entire supply chains does not necessarily reduce risk; it simply shifts a country's dependence to a single source. Stepping back from utilizing these trade networks could also mean forfeiting the substantial welfare gains generated by interconnected transport systems as we have outlined above. An open direction for future research is to examine both sides of this trade-off: the global welfare gains arising from reliable and efficient transport networks, and the far-reaching consequences of local disruptions that propagate through these same systems.

One additional area of open research is how these hubs come about. Some hubs are largely geography-driven, reflecting the natural topology of trade routes (for example, the Suez Canal, the Straits of Malacca, or the Panama Canal), while others are institutionally constructed through deliberate infrastructure investment and policy coordination (for example, the emergence of entrepôt economies such as Singapore and the United Arab Emirates). Additionally, ports have also been established for geopolitical reasons. We discuss this next.

7 Geopolitical Effects

So far, we have focused on the economic benefits and costs of port development. Yet throughout history, ports have also been established for geopolitical reasons. For instance, the treaty ports that Western powers forced open in China after the mid-19th-century Opium Wars facilitated trade while projecting naval power (Fairbank, 1969). More recently, port ownership became more globalized in the 1990s, when several countries privatized their port infrastructure or operations in an attempt to increase port efficiency and reduce bottlenecks. The current degree of liberalization varies widely across countries, but a common arrangement is public ownership of a port authority combined with privately owned terminal operators. Full privatization has been limited to a few cases such as the United Kingdom (World Bank, 2007, 2025).

Early international port operators included privately owned companies such as Hutchison (Hong Kong), Maersk/APM Terminals (Denmark), or MSC/TIL (Switzerland), and state-owned companies such as DP World (United Arab Emirates) or PSA International (Singapore). As documented in Stylized Fact 4, China's two state-owned companies COSCO Shipping Ports and China Merchants Port expanded rapidly over the last two decades (see Figure 2). Including Hutchison, the three Chinese operators accounted for 17.4% of global throughput in 2024.[14] Overall, Chinese private- or state-owned firms own or operate approximately 2,000 domestic and 100 foreign ports (Kardon and Leutert, 2022). In contrast, the US has only 208 domestic ports, and none of the top global terminal operators in Figure 2 are US-based (Runde, Hardman and Bonin, 2024).

This expansion has raised concerns about China's potential non-economic motives in other countries, leading to regulation by the US and the EU to limit foreign ownership that could pose security risks (Nightingale, 2025).[15] Besides rapid growth, several features make China an unusual owner relative to other private or state owners, increasing the potential to leverage ports for geopolitical aims. First, the level of state control is particularly high—either directly through state-owned firms or via special influence over privately owned firms; for example, Hutchison's top executives are appointed by the Chinese government (Kardon and Leutert, 2022). Second, the development of specific trade routes is an explicit government objective, and the shipping industry has been named by the government as one of seven sectors designated for absolute state control (Kardon and Leutert, 2022). Finally, Chinese port operators exhibit a high degree of vertical integration across related maritime industries such as shipping, shipbuilding, port construction, and logistics services, which can confer substantial market power (Ghiretti et al., 2023; Runde, Hardman and Bonin, 2024). This vertical integration is reinforced by China's dominance in shipbuilding (Barwick, Kalouptsidi and Zahur, 2025): in 2025, China accounted for more than half of global production in every major vessel class (Chowdhry, Heiland and Mahlkow, 2026). The deep-integration of Chinese-built vessels into global shipping networks—evidenced by the fact that non-Chinese firms operate the majority of Chinese-built containerships, highlights systematic vulnerabilities arising from China's

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[14] In March 2025, a US-based consortium led by BlackRock announced a deal to acquire a majority stake in Hutchison after US President Donald Trump raised concerns about the presence of China-based companies at the Panama Canal (Jim and Murdoch, 2025).

[15] US: Foreign Investment Risk Review Modernization Act (FIRRMA), enacted in 2018; EU: EU Regulation 2019/452, enacted in 2019.

dominance in these critical maritime margins (Fuchs, Leibovici and Wong, 2026). The resulting concentration has prompted its own policy responses, including plans by the US government to charge substantial port fees on China-linked ships from November 2026 (USTR, 2025).

Against this backdrop, we use China's recent expansion in foreign port ownership as a case study to assess potential geopolitical concerns about port control. Our Stylized Fact 5 documented the operational consequences of Chinese port ownership; here, we examine three mechanisms through which port ownership could confer geopolitical benefits to China. First, ports are inherently dual-use assets: beyond facilitating trade, they confer military benefits by providing access to naval vessels, military logistics, and intelligence. Second, through strategically located ports and port development, owners can influence trade routes and build geopolitical leverage by creating economic dependence. Third, certain ports are critical bottlenecks in the maritime transport network (as also discussed in Section 4). In times of shortages (e.g., during the recent pandemic), owners can ration scarce resources, creating geopolitical influence by granting, delaying, or denying port services to vessels from particular countries.

7.1 Dual-use: military objectives

In contrast to the US, China officially operates only one overseas military base, in Djibouti. To assess the potential military use of China's global port operations, Kardon and Leutert (2022) evaluate 96 Chinese-operated, foreign ports in 53 countries along four criteria: (i) military usefulness of geographic port locations, (ii) state potential for operational control of ports, (iii) physical capacity to support naval vessels and operations, and (iv) military track record and motive. China scores very high on the first criterion, since many of these ports are close to maritime choke points (which also serve economic interests), key sea lines of communication, and potential conflict areas. State control is also high, as many ports are operated by SOEs and often hold majority stakes. Ownership on foreign soil, however, faces limits: in wartime or crisis, host states can curtail foreign firms' control over domestic infrastructure. By contrast, most Chinese-owned foreign ports have limited capacity to accommodate naval operations, though they can be used to collect maritime intelligence.

With respect to motive, China's naval presence in important sea straits appears intended to ensure free trade routes to Europe. For example, by using the Greek port of Piraeus to accommodate naval vessels dealing with piracy in the Gulf of Aden (Montesano, van de Ven and van Ham, 2016). However, evidence suggests that this military use will continue and expand. Already, at least one third of Chinese-owned foreign ports have experienced calls by Chinese military ships. In addition, there have been indications that information on foreign ships calling at Chinese-owned ports is collected and used by the Chinese military. China's ongoing civil-military integration program suggests that these activities may expand rather than diminish (Kardon and Leutert, 2022).

Overall, the military potential of China's foreign port operations is already high and appears to be growing. Geographic suitability and state control are high, and while physical capacity is still limited, China's motive for military use appears to be increasing. Other countries that own very large port operators differ from China in important ways: some have lower state control over operators (e.g., Denmark, Switzerland), and others—such as Singapore—have not signaled comparable military use of foreign ports. The UAE is an exception, where ports form part of its military strategy in the Horn of Africa (Kocak, 2020; Vertin, 2019).

7.2 Creation of economic dependence

Port ownership can be used to create economic dependence, which in turn can be translated into geopolitical leverage (Hirschman, 1980). This can play out locally at the level of port cities: if a port city's economy is highly reliant on its port, local policymakers may hesitate to confront the port's owner politically (Ghiretti et al., 2023). It can also operate at the national scale: by lowering trade costs, ports form or deepen economic relationships between countries. This effect extends beyond the owner's country and the host country, as efficient ports can develop into transportation hubs linking third countries (e.g., Piraeus in Europe–China trade; see Koenig et al. 2024). Economic ties through trade can yield political power when countries threaten to interrupt trade (what Hirschman (1980) terms the "influence effect of foreign trade"). This logic creates an incentive for countries to use foreign port investment to increase other countries' economic dependence (Waltz, 1979).

However, ports may not necessarily increase economic dependence. On the one hand, ports can reduce dependence on particular partners by enabling access to alternative buyers or suppliers. On the other hand, interrupting trade imposes costs on the threatening country as well. An important question is whether the gains from trade are shared relatively equally between trading partners (creating mutual dependence or interdependence) or whether the division is asymmetric (creating one-sided dependence).

There is mixed empirical evidence on how much economic dependence China's port expansion has created. On the one hand, about 90% of China's goods trade moves by sea, compared with a global average of 80%, suggesting that China may be more dependent on ports than other countries (UNCTAD, 2024; Kardon and Leutert, 2022). Furthermore, there is evidence that countries that participated in OBOR experienced an increase in their number of trading and FDI partner countries, suggesting reduced reliance on any single country (Lu et al., 2024).

On the other hand, China has become the top trading partner for more than 120 countries, suggesting potential leverage (Runde, Hardman and Bonin, 2024). China's leadership itself has also stated an objective to increase foreign supply chains' dependence on China (Kardon and Leutert, 2022). Recent evidence suggests that China has been successful in reaching this goal. Dependence measures constructed from structural-gravity trade data show a sharp rise in other countries' dependence on China, accounting for access to alternative suppliers for intermediate inputs and consumer products. China's port policies have contributed to this trend: Countries that received Chinese financial assistance under the OBOR initiative became more dependent on China, whereas China's dependence on those countries did not increase (Mangini and Chaudoin, 2025).

7.3 Control over bottlenecks

Recent disruptions in maritime shipping—for example, Chinese port closures during Covid-19, the Ever Given blocking the Suez Canal in March 2021, drought-related restrictions at the Panama Canal, conflict-related risks in the Red Sea, and the 2026 Strait of Hormuz crisis—have highlighted the vulnerability of global supply chains, as large volumes of trade depend on a few bottlenecks in global maritime routes.

Bottlenecks are nodes or links in the transport network for which alternative routes are costly, that is, not easily substituted. Common examples are man-made canals such as the Suez Canal (with the Bab al-Mandeb Strait on its southern approach), which avoids a 5,000-nautical-mile detour between Europe and Asia, and the Panama Canal, which avoids an 8,000-nautical-mile detour between the Atlantic and Pacific Oceans. Natural straits that function as bottlenecks include, among others, the Strait of Hormuz, the only sea passage from the Persian Gulf to the open ocean, and the Straits of Malacca, the fastest sea route between the Middle East and East Asia.

Because they save time and cost, a large share of international trade passes through these chokepoints. For example, 9.8% of German imports transit the Suez Canal, and 8.7% pass the Straits of Malacca. For specific products with few alternative suppliers, dependence can be much larger: 97.2% of German crude mica imports, a key input for electronics and construction, pass through the Suez Canal (Bodenschatz et al., 2025). The Strait of Malacca is also a chokepoint in the opposite direction: about 80% of China's oil imports pass this route (von Grafenstein, Jetzig and Zydra, 2025). Closing these chokepoints would severely impact global trade, with the largest estimated declines for the Panama Canal (-3%), followed by the Suez Canal (-2.5%) and the Straits of Malacca (-1.7%) (Maurer, Milsom and Rauch, 2026).

Bottlenecks become most salient when commonly used routes are disrupted. While existing research has identified chokepoints and estimated the economic impact of disruptions, less attention has been paid to how the nationality of a port owner could generate geopolitical implications. In situations of scarce capacity at ports or along maritime routes, the identity of the owner of the scarce asset can become relevant because the operator decides allocation: which ships may call, which ships are prioritized, and who can use which facilities. Through control of bottlenecks, global trade flows can be influenced.

How relevant is the control of maritime chokepoints as a motive for Chinese port ownership, and what are the effects? China explicitly emphasizes control of "key passageways, junctions, and projects" in its strategy. Consistent with this, Chinese-operated ports are disproportionately located near chokepoints: about 55% of China's overseas port projects lie within 480 nautical miles of major chokepoints, especially around the Suez Canal, the Strait of Malacca, and the Strait of Hormuz (Kardon and Leutert, 2022).

8 Conclusion

At first glance, maritime trade works today as it has for centuries: goods are loaded onto ships at ports and carried across the seas. This review has documented that beneath this continuity, the network that moves the world's goods—which cities handle global cargo, how shipments are routed from origin to destination, and who owns the infrastructure they pass through—has been transformed by containerization and related technologies. For decades, the consequences of this transformation for ports and their host cities remained beyond the reach of systematic study because the necessary data did not exist. The recent proliferation of granular data—digitized historical shipping records, georeferenced ship movements, and shipment-level routing information—has changed this, and we have organized our synthesis of the resulting literature around five stylized facts drawn from such data on the concentration, dispersion, churn, and ownership of global port activity.

Three broad lessons emerge. First, the effects of transport technologies are heterogeneous across space. Containerization changed the inputs that shipping requires, favoring cities with natural depth and abundant land while crowding out other activity where land is scarce. Port development thus carries real opportunity costs, particularly in high-productivity cities. Second, the network structure these technologies created magnifies both their benefits and their costs. Hubs deliver outsized welfare gains, give even small countries access to cheap large-scale transport, and link ports into multimodal networks whose complementarities raise the returns to infrastructure investment. The same concentration generates market power, congestion, environmental damage, and fragility when critical nodes are disrupted. Third, precisely because critical nodes are valuable, who controls them matters. State ownership of port infrastructure has grown rapidly. This raises questions about whether port control can serve military objectives, build economic dependence, and confer influence over chokepoints—particularly where the dependence created is asymmetric rather than mutual.

These lessons carry direct implications for policy. For infrastructure investment, returns are highly uneven and depend on the network: welfare gains are concentrated at hubs, investment is worthwhile only at a subset of ports and particularly where it decongests other parts of the network, and evaluations that ignore multimodal interactions can substantially understate both the gains from improvements and the losses from disruptions. Because shipping networks span borders, the benefits of one country's investment, as with the Panama Canal expansion, accrue in large part to others. For environmental regulation, the central challenge is that targeted policies trigger offsetting responses: ships re-route around regulated waters, emissions shift toward land, and capping carbon emissions from maritime shipping can raise total transport emissions by diverting cargo to far more carbon-intensive air freight. Finally, the rapid growth of state ownership of port infrastructure has already prompted policy responses, including investment-screening regimes in the United States and the European Union and planned US port fees on China-linked ships, while the leverage such ownership ultimately confers depends on whether the dependence it creates is asymmetric or mutual.

These lessons and policy challenges also provide directions for future research. The consequences of market power in maritime shipping remain incompletely understood, as do the interactions between transport networks and the environment: how large the environmental costs of the unprecedented growth in world shipping have been, which parts of the world bear them, and how climate change will reshape the way goods can be transported. Another open question is why and how hubs emerge—through geography, deliberate institutional investment, or geopolitical strategy; for the latter, a priority is to identify and quantify bottlenecks in the maritime system and the dependencies they create. Underlying all of these questions is a fundamental trade-off. Interconnected transport networks generate large global welfare gains, but they also transmit local disruptions far beyond where they originate. The proliferation of new granular data make it possible to measure both sides of this trade-off directly. Progress here will shape our understanding of the balance between efficiency, resilience, and control of critical nodes in transport networks.

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Appendix

Appendix A Worldwide shipping data, 1951 and 2008

We use a unique dataset of worldwide port calls for 1951 and 2008 based on the *Lloyd's Shipping Index*, a daily record of merchant vessels arriving at ports worldwide. The data were digitized and constructed by Ducruet, Cuyala and El Hosni (2018) using one-week samples from the first week of May in each year, where each observation corresponds to a ship arriving at a port at a particular point in time. The dataset is distinctive in its combination of long time span and global port coverage.

Following Ducruet et al. (2024*b*), we match port calls to known ports in either the 1953 or 2017 edition of the *World Port Index (WPI)* (United States Hydrographic Office, 1953; National Geospatial-Intelligence Agency, 2017), and aggregate ports to cities (including their urban agglomeration areas) based on Ducruet, Cuyala and El Hosni (2018). Port calls that cannot be matched to the WPI or assigned to a city, such as offshore terminals, are dropped. Cities are then ranked by their total port calls in the respective year.

Appendix B Chinese port ownership and port calls

We combine port call data from *Global Fishing Watch* with Chinese port ownership data from Banach and Gunter (2024) and ship operator information from EconDB to assess how Chinese ownership affects port operations.

Sources:

- Global Fishing Watch: Copyright [2025], Global Fishing Watch, Inc., `https://globalfishingwatch.org/our-apis`. Dataset accessed April 22, 2025.
- EconDB, Vessels – vessel characteristics database, `https://www.econdb.com/maritime/vessels`. Dataset downloaded May 20, 2025.

Out of 74 Chinese-owned ports identified in Banach and Gunter (2024), we restrict our analysis to takeovers by Chinese state-owned port operators that occurred between 2012 and 2024, the period for which we have shipping data. We define takeovers as control of TEU capacity exceeding 40% of the port's capacity. Control of TEU capacity at a port equals the ownership share of the terminal-operating company multiplied by the terminal's TEU share of the port. Port TEU capacities were manually collected from online sources. Fifteen takeovers in 14 countries satisfy these criteria. Ship turnaround time per port is defined as the median number of hours between arrival and departure during a port call. We drop ship turnaround times of less than 3 or larger than 72 hours.