Competition and Coordination in Infrastructure: Port Authorities' Decisions to Become "Big Ship Ready"

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Abstract

Who should build infrastructure and how much should they build? In the United States, transportation infrastructure decisions are mostly made at the state or local level. I study seaports during a period when massive investments were being made on the East Coast to prepare for the larger vessels that could navigate an expanded Panama Canal. If ports do not internalize their business-stealing effect on others, there may be overinvestment–especially with subsidization. On the other hand, there may be underinvestment if ports do not internalize the benefits of increased variety. With data on all container imports and capital costs of the major US ports, I estimate a model of the investment game that port authorities play with one another. I find there would be much more investment on the East Coast if ports coordinated their activities and that its spatial distribution would be much different.

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1 Introduction

In the United States regional authorities often compete with one another. There has been a long line of research since at least Charles Tiebout in 1956 studying when this competition is more efficient than a centralized government. When businesses and residents have heterogenous costs and preferences, variety among regions can be beneficial. However, there may also be Prisoners' Dilemma scenarios, where both regions would benefit by committing to a lower level of investment. These investments are frequently subsidized by outside authorities, so lower levels may be beneficial not only to locals but the entire country.

Over the past ten years there has been a flurry of infrastructure investment by port authorities on the East Coast in response to the expansion of the Panama Canal, announced in 2006 and completed in 2016. The Canal grew to allow a ship size almost three times the pre-expansion maximum. Larger ships can carry more containers with the same size crew and proportionally less fuel, so there are increasing returns to scale. However, these economies of scale are wasted if a port is not deep enough to allow the ship to unload. These authorities are all regional. They rushed to invest to make their ports more attractive to importers without internalizing the effects their investments would have on the business of other ports.

In this paper, I study whether competition between port authorities has led to excess or insufficient investment in container ports. By "excess investment" I mean investment that does not increase social welfare more than it costs. I estimate substitution patterns between ports using a hand-collected panel of port characteristics and the universe of waterborne container imports, which includes the money spent on investments to prepare ports for larger ships possible after the Panama Canal expanded. Using these substitution parameters and economies of scale parameters estimated from other work, I model the investment game port authorities play. These data are detailed enough that I can generalize the port authorities' objectives beyond that of profit-maximizers, and so my welfare results take seriously what the port authorities are actually striving for.

Though there has been a long literature studying regional competition, there has been relatively little focusing on infrastructure investment. This is surprising, given 1) infrastructure spending is a large part of state total spending and 2) most infrastructure spending in the US is done on the regional level. For example, firm-level tax incentives, which have been the subject of much research, totaled a little under \$50 billion in 2015 (Bartik 2019). By comparison, state and local governments spent around \$340 billion on transportation and water infrastructure in 2017. This is a large amount in dollar amount but also as a fraction of total infrastructure spending. In the same year, federal spending was below \$100 billion, less than one-third that of states and localities (Office 2018).

I focus on container ports, which possess the unique features of all transportation infrastructure and are economically important in their own right. These are a vital part of US international trade: about half of trade by value is waterborne, and about half of waterborne trade is containerized (Chambers and Liu 2012). There is a large amount of investment in these ports. In a 2012 survey, ports reported plans to spend \$18.3 billion dollars over the next four years, and \$22.6 billion from 2016-2020 (Port Authorities 2016). All of these spending decisions are made by authorities often responsible to governments as small as municipalities. They may even be neighboring: Los Angeles and Long Beach are controlled by different port authorities, despite being less than five miles apart and in the same bay.

In order to say whether there is over- or underinvestment, I need an efficient benchmark for what "optimal investment" looks like, and for this I need a model of the main agents involved: importers, carriers, and especially port authorities. Importers are located in particular places in the U.S. and ship goods from particular places abroad. They choose which port to have their good sent to, taking as given characteristics of the port (including the port's distance to the importer). Given their quasi-public nature, we should expect authorities to not be pure profit maximizers, so I model their objective as a weighted average of profit and total imports. They compete with one another by investing in harbors that can accommodate larger ships, and these investments are subsidized by the federal government. Because larger ships have lower average costs, ports increasing their capacity is the equivalent of those ports shortening the distances between them and foreign origins. Thus though these investments are costly, they lower the effective price of importers who choose them.

I estimate economies of scale and substitution parameters and then use these to consider an optimal counterfactual. I find economies of scale are quite high, with average cost elasticities of 0.2-0.33.[1] Even for smaller vessels, the relative costs of shipping by land compared to ocean are much higher. These results tell us both economies of scale and product differentiation, but by themselves do not say which force dominates.

To understand which force dominates, I consider the counterfactual where in 2016, ports on the East Coast coordinate with each other to maximize joint surplus. I find there to be more investments under the coordination than under competition. Whereas only Miami expanded in 2016 in the data, in the counterfactual Wilmington, Charleston, Savannah, and Houston invest. I also find which objective authorities are using makes a large difference: if the ports value quantity for its own sake, beyond any additional profits, New York & New Jersey is also invested in in 2016 (rather than 2017). Acting independently, the ports thus tend to underinvest. Coordinating their activity raises the surplus of the port authorities and, because the importers value the investments made, that of the importers as well.

2 Literature

Many researchers have studied the effects of transportation infrastructure on total output or productivity; see (Turner, Duranton, and Nagpal 2020) and (Ramey 2020) for recent overviews. There is no clear consensus on how important it is for output, but most acknowledge that the efficiency of transportation infrastructure varies greatly over space and time. (Turner, Duranton, and Nagpal 2020) find social welfare weights for several different modes of transportation and compare these to the implicit weights from government spending. They find the two sets of weights are wildly different, meaning infrastructure investment is inefficient. However, this and other papers study optimal national policy when states are not strategic agents. Outcomes that may seem inexplicable when there is a single planner, such as excessive investment in some areas, make much more sense when we consider that the investing agents are sometimes working at cross-purposes with one another. The paper closest to mine in this strand is (Hulten and Schwab 1997), who study the effects of tax exemption on municipal bonds and infrastructure subsidies. Because they are looking at

1. That is, increasing ship size by 1 percent lowers average cost per container by 0.2-33 percent. A 8,000 twenty-foot equivalent unit (TEU) ship has average costs 12 to 20 percent lower than a 5,000 TEU one.

aggregate investments, though, they cannot model the oligopolistic game being played by the agents as I do with port authorities.

There is another literature that does study competition between states or localities, starting with(Tiebout 1956). The way states compete in these papers is through fiscal policy (such as tax credits or subsidies) or through public goods consumed directly by households (such as better schools or parks). A recent example is (Slattery 2020), which studies states competing for firms locating there through subsidies. Such competition may be welfare enhancing if there are spillovers, as firms do not internalize the full surplus they generate. My work differs in that I study capital investment rather than fiscal policies. These policies are a much larger fraction of state budgets, about three times as much, as business incentives.

I also draw on results on "excess entry" in the industrial organization literature. A long-standing result is that in markets where a single firm's output decision affects the decision of other firms (i.e., in markets that are not perfectly competitive), there may be excess entry (Mankiw and Whinston 1986). The reasoning is as follows: when a firm chooses to enter, it cares only about its expected payoffs. Upon entry, though, all other firms will reduce their output (or imports in the case of ports). This reduction in output is a cost not internalized by the firm, and as with any negative externality, there will be too much of it in a market equilibrium. The gains from variety are also not internalized by the firm but are a positive externality. Whether there is over, under, or optimal entry depends on which of these effects dominate. This has been studied theoretically by (Mankiw and Whinston 1986) and found to be empirically relevant by (Berry and Waldfogel 1999). Instead of profit maximizers, I study quasi-public authorities who may internalize some of these externalities already. I thus need to generalize the agents' objectives to allow for this fact.

Finally, many researchers in maritime economics have studied competition between ports. (Notteboom and Langen 2015) and (Lee and Lam 2015) discuss the growing devolution of port authority in Europe and Asia, respectively, and how the distribution of trade has changed over time. There has been less work studying competition among U.S. ports, possibly because there has always been less of a country-level port policy in that country. An exception is a Federal Maritime Commission report from 2012, though that focuses on competition between U.S. ports and Canadian and Mexican ports, not competition between U.S.

ports themselves. (Ishii et al. 2013) is a recent example that is closest to my approach. The authors model ports as making capacity investments in alternating periods, and then given those capacities, setting prices simultaneously. They derive several propositions whose results they compare to the ports of Busan and Kobe. My model of port investment is very similar to theirs; however, the bill of ladings microdata allows me to actually estimate the model, rather than derive only qualitative results.

3 Background

3.1 Port organization

Unlike many other countries, there is no single agency that administers U.S. seaports. Instead, they are governed by a variety of state, municipal, and regional authorities. Though all these authorities are ultimately responsible to elected officials, their operational independence varies: for example, the Massachusetts Port Authority is explicitly chartered to *not* be subject to control by other agencies, whereas the North Carolina State Ports Authority is within the state's transportation department (Sherman 2008). In some cases, the authority board of commissioners is required to have at least some members from parts of the state far from the port, to guarantee the welfare of more than just the port city is being considered (Sherman 2008). There are also differences in funding: most of the larger ports can cover their own operational costs, but may receive funding for select capital projects from the state or local governments. Others may have a guaranteed revenue from the state coming out of a specific tax or trust. The Virginia Port Authority, for example, receives revenue from the Commonwealth Port Fund, which is tied to highway taxes (Joint Legislative Audit and Review Commission 2013).

Outside of government revenue or bonds, port authority's revenue comes from two major sources: rentals and the fees charged to ships that enter on its own terminals. There are many different kinds of fees for things like crane usage, refueling, water usage, etc. The main ones are wharfage, which is a per-weight or per-container fee for unloading, and dockage, which is a per-ship fee for docking at the port (though the fee will usually vary depending on the size of the ship) (American Association of Port Authorities 2019). From the information available, wharfage is the larger of the two. For example, out of the approximately $398 million the Port of Los Angeles made from shipping services in 2017, $369 million, over 90%, were from wharfage. I thus feel comfortable treating ports as setting a per-container price that importers respond to.

I focus on containerized imports. Though ports are in the business of other types of imports, there are several advantages to focusing on containers. First, for most of the largest ports, containers are the primary source of revenue from shipping services. For the Port of Los Angeles, about 93% of imports by weight were from containers, and even more by revenue (Finance and Port of Los Angeles 2019). Second, containers are, by design, standardized. It is rare for two containers of the same volume to be charged different rates, regardless of commodity or even weight. (In theory, heavier containers may be charged more, but it is rare for weight rather than volume to be the limiting factor (Holmes and Singer 2018).) Finally, because containers are often not opened until near the end of their journey, the port of entry (where it goes through customs) may be different from the port of unlading (where it comes off the ship). This allows me to see from customs data alone not only where a container physically entered the United States, but where it was unpacked.

There are three important facts about ports that I need to consider. First, U.S. port authorities are usually responsible to some elected body. The Port of Long Beach commissioners are appointed by the mayor of Long Beach; in other ports, the appointing official may be the state governor or pair of governors. It is misleading to think of those authorities as pursuing the same goals as a for-profit, private firm, and indeed, the demand parameters I estimate do not make sense for a profit maximizer. A contribution of the paper is building a more general objective for the port. Second, almost every port is run independently. While there are exceptions—ports in the Southeast are operated by the same state agencies and Seattle and Tacoma have recently joined under a single authority—the standard is for ports to be separate, even if they are geographically very close. For example, ports like Los Angeles and Long Beach, or Miami and Port Everglades in Fort Lauderdale, are separate. Finally, port infrastructure (dredging, cranes, rail lines, etc.) demands large initial costs, but once these are paid, the cost of unloading an additional container is very small. In industries with this cost structure we often expect concentration to be increasing as larger firms can invest in new equipment that lowers their per-unit cost, allowing them to become even bigger. That is exactly what we see in container ports. The top 10 accounted for 78% of imports in 1995, and for 86% in 2008. The number is even higher now (Bureau of Transportation Statistics).

3.2 Panama Canal expansion and container shipping

In 2006, Panamanians voted to add two new locks and to deepen existing channels. The decision was due in part to the growing size of containerships. As late as the mid-1990s, there was no containership in the world that exceeded the roughly 5,000 twenty-foot equivalent units[2] (TEU) of the Panama Canal. Around a decade later, when the plans for expansion began, the average size of a newly built ship was still below the limit. That was not the case when the expansion was finished, on June 26, 2016. By that point, the largest ships in the world were almost 20,000 TEU, and the average newly built ship was around 7,500 – well above the previous maximum allowable size. (Merk, Busquet, and Aronietis 2015). The new maximum of about 13,000 TEU was more than twice as large as the previous maximum.

There would have been no reason for the Canal to expand if it were not for the large economies of scale that exist for container ships. Average cost is almost always decreasing, limited only by demand and the the infrastructure of canals and ports. There is "engineering" evidence of this: the resistance of water increases with the surface area of the vessel, not the volume. We can also see the economies of scale from the behavior of the carriers. Almost immediately after the expansion, carriers that had weekly services of two vessels around the maximum capacity switch to weekly service of only one larger vessel. Overall, the average vessel size of shipments from East Asia to the U.S. East Coast (which often though do not always go through the Panama Canal) increased by around 2,000 TEU following the expansion.

For my research, the Canal expansion is important because it spurred ports on the East Coast to invest in becoming "Big Ship Ready." These investments were dramatic. The Bayonne Bridge, one of the largest steel arch bridges in the world, was raised over 50 feet

2. One twenty-foot equivalent unit (TEU) is one half a standard 40-foot container.

at a cost of \$1.7 billion in order to allow larger ships to enter the Port of New York and New Jersey. The Port of Savannah is currently near the end of a dredging project that deepened the harbor by 5 feet and cost over \$970 million ("Bayonne Bridge Expansion Pays Big Dividends for Port of N.Y.-N.J." 2020). These projects all began after the decision to expand the Panama Canal was announced, and were explicitly presented as necessary because of the expansion. The ports also recognized that their investments would pay off potentially at the expense of other ports (Booth 2013).

4 Data

4.1 Port characteristics

Data on port characteristics come from port authority financial reports and various news sources. The physical characteristics I focus on are harbor depth and, if applicable, the air draft or height limit due to bridges. There are other forms of capital ports invest in such as rail connections or warehouse areas, but these two are especially important as they limit the maximum ship size. There is a rarely a hard cap, but something like a shallow harbor depth can make it more costly for a carrier to enter with a larger vessel. For example, in 2006, the carrier MSC started sending 6,700 TEU vessels to the Port of Savannah. The draft of these vessels when fully loaded was 48 feet, more than Savannah's harbor, so MSC was obliged to send vessels that were less than fully loaded. This either meant a more complicated scheduling problem or losing some of the economies of scale advantages of a larger ship. They also required high tide and thus could only enter during specific times of day. Eventually, this proved too cumbersome, and MSC switched to sending many of the larger vessels to Charleston, with goods intended for the Savannah market trucked down (Engineers 2012).

In Table 1 are the range and median ports depths on each coast. During this period, most of the growth was from the East Coast expanding to the same depths as West Coast ports. West Coast harbors are for the most part naturally deeper. There is also no canal constraining ship sizes from East Asia to the West Coast, and so most had already adopted to larger ship sizes by this time.

	East Coast		West Coast	
	Range	Median	Range	Median
2014	40–50	43	50–53	51
2015	40–50	44	50–53	51
2016	40–51	45	50–53	51
2017	40–55	45	50–53	51
2018	40–55	45	50–53	51

Table 1: Maximum Berth Depth (ft.)

Perhaps the most important feature of ports is one over which the authorities have no control: where the port is physically located. Figure 1 shows the map of the ports that I consider in my market. There are two things to notice. First and most obviously, the North American landmass separates ports on the East and West Coast. Carriers going from East Asia to the East Coast must decide whether to unload on the West Coast and ship by land or go through the Canal, subject to the constraints that imposes. Second, ports are not distributed uniformly. The East Coast is more densely filled than the West. There are also many "twins," ports that are separate but very close to one another, like Los Angeles and Long Beach, Seattle and Tacoma, or Miami and Port Everglades. These facts suggest that substitution patterns likely vary across ports.

4.2 Container imports

All imports to the United States file a bill of ladings with United States Customs and Border Protection (CBP).[3] These contain the date entering the U.S., the vessel the shipment came on, the foreign port it came from, the U.S. port it entered, and the U.S. customs office it went through. These last two variables, the "port of unlading" and "port of entry," respectively, are important in proxying for the land distance traveled. I merge these bill of ladings data with vessel characteristics like container capacity from http://www.vesseltracking.net.

The purpose of the shipping industry is to turn goods that are far away into goods that

3. I thank Tom Holmes for providing these bill of ladings data.

Figure 1: Map of ports in sample

are nearby, and so it is critical that the distances I use are realistic. Land distances are the fastest route by car using the Google Maps API. For the sea distances, the straight-line is less likely to be a good approximation and so I use publicly available data on the actual travel distance between ports. For ships that could go through the old Panama Canal, or "Panamax sized ships," I assume they always take the shortest path, which may or may not go through the Panama Canal. For ships larger, called "post-Panamax," if they are also under 13,000 TEU, I assume they take the shortest non-Panama distance before the canal expanded and the shortest distance, including Panama, afterwards. For ships larger than 13,000 TEU, I assume they always take the shortest non-Panama distance.

Tables 2 and 3 display the average distances traveled by land for containers and sea, respectively. The majority of containers go through customs in the same port as their ship arrives, so the median distance traveled on land is zero. To give a sense of what these distances refer to, 2,211 km is the distance between Los Angeles and Houston. For sea, 10,601 km is the distance between Yantian (a district in Shenzhen in southern China) and Los Angeles. Over this entire period, the distance between the port of unlading and the final destination is falling. The sea distances are growing before 2016, when they fall, but they begin growing in 2018 again. This drop is likely due to containers that might previously have gone on large vessels through Suez instead going through Panama. Over time, the average importer is preferring ports that are closer by land at the expense of sea.

Year	Mean	Median	Mean (>0)	Median (>0)
2014	462	0	1,994	2,211
2015	414	0	1,936	2,193
2016	391	0	1,894	2,192
2017	371	0	1,816	1,990
2018	367	0	1,795	1,990

Table 2: Land distances (km)

If importers are preferring longer sea travel, it must be because sea travel is becoming cheaper relative to land. In Table 4, we see that the size of vessels has been growing over

Year	Mean	Median
2014	12,166	10,571
2015	12,459	10,660
2016	12,300	10,601
2017	12,207	10,601
2018	12,334	10,601

Table 3: Sea distances (km)

time. Given the economies of scale in shipping, this leg of the journey has become cheaper.

Year	Mean	Median
2014	6,465	6,350
2015	6,796	6,600
2016	7,061	6,763
2017	7,504	7,500
2018	7,728	8,000

Table 4: Vessel size (twenty-foot units)

5 Model

To say whether investment is excessive or insufficient, I need a way to compare the costs to the benefits it brings importers and ports. There is a trade-off between the economies of scale from concentrating shipping and the benefits of variety. To accurately measure the benefits I build on standard discrete choice demand models, incorporating important, individual-level features of this market: the economies of scale in ocean shipping, ocean distance, land distance, and port fee at the container level. For the costs I model the ports as choosing a level of investment that determines the largest ships that can unload there. Investment is expensive but indirectly lowers the cost for importers, bringing them to the port. Port authorities care about ships entering ports because it increases profits, but they also care about the total quantity for its own sake.

5.1 Overview

Importers have inelastic demand for containers from a foreign origin port o in U.S. location d. Origin ports are always container seaports; the U.S. locations may be a port or an inland location. Importers choose the seaport that minimizes the total cost of moving the container. There is a trade-off between ports that are expensive to get to by land but which may have low prices for the ocean leg of the journey. The total number of containers going from origin o to seaport (not final destination) j is $q_{o,j}$.

Ocean carriers move containers from foreign ports to domestic ones. They take as given the total number of containers being shipped on the route, and choose the size of the ship to minimize average cost.

Land carriers are a competitive sector that charge a constant price per unit distance.

Ports behave strategically, taking as given the actions of other ports. Their main decision is whether to invest in infrastructure that allows post-Panamax vessels to unload there.

5.2 Importers

I assume importers make decisions separately for each container. They consider the price of moving the container by land from the domestic port to the final destination, $p_{land,j,d}$ and the price of moving it by sea from the foreign port to the domestic, $p_{sea,o,j}$. I allow each port to have an unobserved cost for all importers, ξ_j. This may be how quickly the port can unload ships, or an especially valuable rail connection. Finally, importers bear some individual cost shock, ε_{ij}, that is independent and uncorrelated with any other port feature.

The importers face the problem

$$\max_{j \in J} -\alpha \left(p_{sea,o,j} + p_{land,j,d}\right) + \xi_j + \varepsilon_{ij} \tag{1}$$

5.3 Ocean carriers

Ocean carriers take the quantities going from foreign ports to domestic ones as given. They have an increasing returns to scale technology and choose the ship size S that minimizes average cost, subject to the constraints of canals or ports. I model the choice of vessel size in a reduced-form manner as a function of the total route quantity, and domestic port capacity. (I assume foreign ports are not a binding constraint.) Let the vessel size be S and $S_{o,j} = S(q_{o,j}, \omega_j)$, where ω_j is the "maximum" allowed at port j. $S(\cdot, \cdot, \cdot)$ is increasing in all three terms. No ship is "too large" to enter any port; however, it is very costly for larger ships to enter ports that are not Big Ship Ready.

After choosing the vessel that minimizes average cost, carriers simply charge this cost to the importers. In reality, the ocean carrier market is itself imperfectly competitive, and they likely charge a markup over their cost. For simplicity I abstract away from any strategic behavior on the carriers' side. As long as the price moves in the same direction as the costs, the direction of my results should still hold, and the magnitudes should not be too far off if markups are reasonably constant.

The carriers solve

$$p_{sea,o,j} = \min_{\substack{S \geq q_{o,j}; \\ S \leq Canal_{o,j}}} f(S, D(o,j); \beta_{sea}) + p_j + \varphi(S, \omega_j) \tag{2}$$

where p_j is the per-container port fee charged by port j, $D(o,j)$ is the distance from origin o to port j, and $\varphi(\cdot, \cdot)$ is a function of ship size and port size. f is the average cost of moving a container on a ship of size $S_{o,j}$ the distance $D(o,j)$ with parameter(s) β_{sea}. In estimation, I parameterize this function based on work studying the economies of scale in ocean shipping.

5.4 Land carriers

Land carriers are a competitive industry that charge marginal cost per unit distance β_{land}. Thus $p_{land,j,d} = \beta_{land} D(j,d)$.

5.5 Port authorities

Port authorities play a game with each other in two stages: first, they choose whether or not to be Big Ship Ready, ω_j. Then, they set prices to maximize a weighted average of profits and total quantity, W_j. I explain the steps in reverse order.

5.5.1 Stage Two

The per-period payoff is

$$W_j = \left[(p_j - mc_j)\, q_j\left(\Omega, a_j, a_{-j}, p_j, p_{-j}\right) \right] + \theta_j q_j\left(\Omega, a_j, a_{-j}, p_j, p_{-j}\right) \tag{3}$$

Port authorities choose the price p_j that maximizes this value, taking as given the prices of other ports, p_{-j} the investment strategies, a_j and a_{-j}, and the state of other ports' preparedness, Ω. The first term on the right-hand side is standard, these are just the profits. The second term multiplied by θ_j is quantity alone, and θ_j is the weight port authority j places on it. Ports are quasi-public entities, and in their public statements often claim to be helping the entire regional economy. If they are purely profit-maximizing this term θ_j will be zero, but if they consider not only their own profits but their employment of workers, or business provided for local firms, it will be positive.

5.5.2 Stage One

Taking the second stage objective functions as given, in the first stage ports decide whether or not to invest. They trade off the cost of investing with the higher q_j of more importers going through.

The ports authorities solve

$$\max_{a \in \{0,1\}} \left\{ \tilde{W}\left(\Omega, a, a_{-j}, \tilde{p}, p_{-j}\right) - \mathbb{1}_{a=1}\left(1 - \sigma_j\right) F_j \right\} \tag{4}$$

where

$$\tilde{W}\left(\Omega, a, a_{-j}, p, p_{-j}\right) = \max_{p} W\left(\Omega, a, a_{-j}, p, p_{-j}\right)$$

and $\tilde{p} = \arg\max_p W\left(\Omega, a, a_{-j}, p, p_{-j}\right)$.

where a is the decision to invest in post-Panamax vessels, F_j is the total cost of port j increasing capacity to post-Panamax, σ is the fraction subsidied by the Army Corps of Engineers or some other outside authority, and a_{-j} is the vector of investment decisions by other ports. The decision to invest is affected by the expected difference in W but also the amount that is subsidized. Clearly if the entire cost were subsidized, $\sigma_j = 1$, ports would always invest.

This model is static; the authorities do not consider their decisions in the future. However, the status of being Big Ship Ready is persistent. For ports which are already Big Ship Ready entering the period, $\omega_j = 1$, I assume that $F_j = 0$, and so the decision is to always "invest" for these port authorities.

5.6 Equilibrium

An equilibrium is a vector of carrier prices, quantities, ship sizes, and investment decisions, $\{(p_{sea,o,j})_{o,j}, (p_{land,j,d})_{j,d}, (q_{o,j})_{o,j}, (S_{o,j})_{o,j}, \vec{a}\}$ such that

1. Taking prices and investment decisions as given, importers solve equation (1).

2. Taking importer quantities and investment decisions as given, carriers solve equation (2).

3. Taking ship sizes, demand, subsidies, and the investment decisions of other ports as given, ports solve equation (4).

6 Estimation and Results

There are three sets of parameters of interest: the economies of scale, the substitution parameters, and the port authority weight on total quantity. Identifying substitution parameters requires costs that depend on economies of scale, and identifying how much authorities weigh quantity requires understanding demand. I present how I estimate each set in this order.

6.1 Economies of Scale

Carriers that use larger vessels have a lower average cost per container, and they pass these savings onto importers. I parameterize the average cost function as

$$f\left(S_{o,j}, D\left(o,j\right); \beta_{sea}\right) = \beta_{sea} \times S_{o,j}^{-\gamma} D\left(o,j\right)$$

where γ is the elasticity of average cost with respect to vessel size. Distance $D\left(o,j\right)$ and vessel size $S_{o,j}$ are observed, thus I need to estimate γ and β_{sea}.

If I could see the costs of each ship, estimating γ would be straightforward: simply regress the logged costs on the logged size, perhaps controlling for year built and builder to account for technological progress. Unfortunately, though I see the individual operating costs of ports I do not have those for specific ships. Instead, I use estimates from work I have done with Tom Holmes. In that paper, we use average charter rates published by Drewry to estimate non-fuel operating costs. For fuel costs, we predict the power necessary to move the ship at its design speed based on its physical dimensions. See Appendix A for more details.

6.1.1 Results

In Table 5 I compare my results to past papers.[4] These authors use different data sources: (Jansson and Shneerson 1978) use data from Zim and the port of Haifa in the early 1960s; (Cullinane and Khanna 1999) use the Fairplay dataset of vessels from the mid-1990s. Nevertheless, the results are fairly consistent across studies. Cullinane and Khanna's elasticity for fuel is an exception: this may be because they assume design speed increases linearly with the size of the vessel. I use the stated design speed and get results much closer to Jansson and Shneerson, who use actual fuel cost data. My total cost elasticity is 0.28. It is not clear what the "total cost" elasticities from the other papers are, though based on the fuel and non-fuel elasticities of Jansson and Shneerson, theirs is slightly higher than mine. In the work that follows I use $\gamma = \frac{1}{3}$, but experiment with other values for robustness.

4. Although I do not use the "capital" elasticity in my estimation, I include it here to show the results are in line with past work.

Jansson and Shneerson (1978)	0.28 (fuel), 0.4 (capital), 0.6 (non-fuel)
Cullinane and Khanna (1999)	0.03 (fuel), 0.24 (capital)
Author's estimates	0.23 (fuel), 0.27 (capital), 0.52 (non-fuel), 0.28 (total)

Table 5: Average cost elasticities

6.2 Demand

I define a market to be all ports in the United States over one calendar year. Although it is not uncommon for carriers to add or remove routes in response to changes in demand, every spring they decide a rough schedule based on anticipated demand and long-term contracts. The port financial reports are issued annually, which makes price vary at the annual level. To make ports comparable, I take averages of values within one calendar year. For example, the Port of New York and New Jersey fiscal year starts January 1, 2015 and the Port of Los Angeles's starts July 1, 2015. For Los Angeles, I treat the 2015 price to be the average of what I gather from the 2014 and 2015 annual reports. Similarly, if a dredging project is completed, say, in October 2016, the 2016 harbor depth is reported as a weighted average of the depth for the first 10 months and the last two.

For simplicity, the price importers pay depends only on distance, port fee, and whether a port is "Big Ship Ready." I define this last characteristic as an indicator for whether a port has a maximum berth depth greater than 45 feet and an air draft above 185 feet. I could interact it with ship size in a binary way, where the ship variable is 1 if post-Panamax and 0 if smaller. Because there is not a strict cutoff, I use a continuous interaction instead. Another possibility would be to estimate this expression and simply remove from the "small" ports from the choice set of larger ships. This would effectively be using a binary variable and taking $\beta_{BSR} \to \infty$. However, as the story above about MSC and Savannah shows, even ports that are not technically prepared for post-Panamax ships can take them in under special (expensive) conditions. Thus including all ports in the choice set of all vessels and allowing β_{BSR} to be a large but finite value is a better approximation than imposing a sharp cutoff.

Importer i's utility from going to port j is

$$U_{ij} = -\alpha \left(\beta_{sea} \times \left(S_{o,j}^{\frac{-1}{3}} D\left(o,j\right) \right) + p_j + \beta_{land} D\left(j,d\right) + \beta_{BSR} \mathbb{1}_{BSR} S_{o,j} \right) + \xi_j + \varepsilon_{ij}$$

The importer is concerned only with the prices paid to the ocean and land carriers and the "port quality" ξ_j, which is further split into a time-varying component $\tilde{\xi}_{jt}$ and a fixed component $\overline{\xi}_j$. (I drop the t in the rest of the equations to reduce notation and because ξ_j is the only place where it matters.) I do not observe these prices, though I do observe cost components like distance, ship size, and port amenities. I use variation between the importers and the Panama Canal constraint to identify importer-specific components like distance, and information on port operating expenses to identify the effect of prices.

I follow (Goolsbee and Petrin 2004). First note that the importer utility can be rewritten as

$$U_{ij} = \delta_j - \alpha \left(\beta_{sea} \times \left(S_{o,j}^{\frac{-1}{3}} D\left(o,j\right) \right) \beta_{land} D\left(j,d\right) + \beta_{BSR} \mathbb{1}_{BSR} S_{o,j} \right) + \varepsilon_{ij}$$

where $\delta_j = -\alpha p_j + \xi_j$. I use maximum likelihood to estimate $\alpha \times \beta_{sea}$, $\alpha \times \beta_{land}$ and $\alpha \times \beta_{BSR}$. If there were no unobserved product characteristic common to all consumers, variation from the consumers would be enough to identify the price elasticity. However, there are likely quality difference between ports that I do not capture with just my measures of distance and capacity. For example, some ports may have faster turnaround times, or refueling may be cheaper. Price is likely to be correlated with these unobserved qualities. I instrument price with the average operating expense per container. This gives me α alone, and from this I can separate the other variables estimated with maximum likelihood.

Assuming the idiosyncratic term follows a Type I extreme value distribution, the probability of importer i importing a good from o to d going to port j is

$$\mathbb{P}_{iodj} = \frac{e^{\delta_j - \alpha\left(\beta_{sea} \times \left(S_{o,j}^{\frac{-1}{3}} D(o,j)\right) \beta_{land} D(j,d) + \beta_{BSR} \mathbb{1}_{BSR} S_{o,j}\right)}}{1 + \sum_{k \in J} e^{\delta_k - \alpha\left(\beta_{sea} \times \left(S_{o,k}^{\frac{-1}{3}} D(o,k)\right) \beta_{land} D(k,d) + \beta_{BSR} \mathbb{1}_{BSR} S_{o,k}\right)}} \tag{5}$$

and the share of containers going to j is

$$s_j = \int \mathbb{P}_{iodj} \phi(i,o,d) di do dd$$

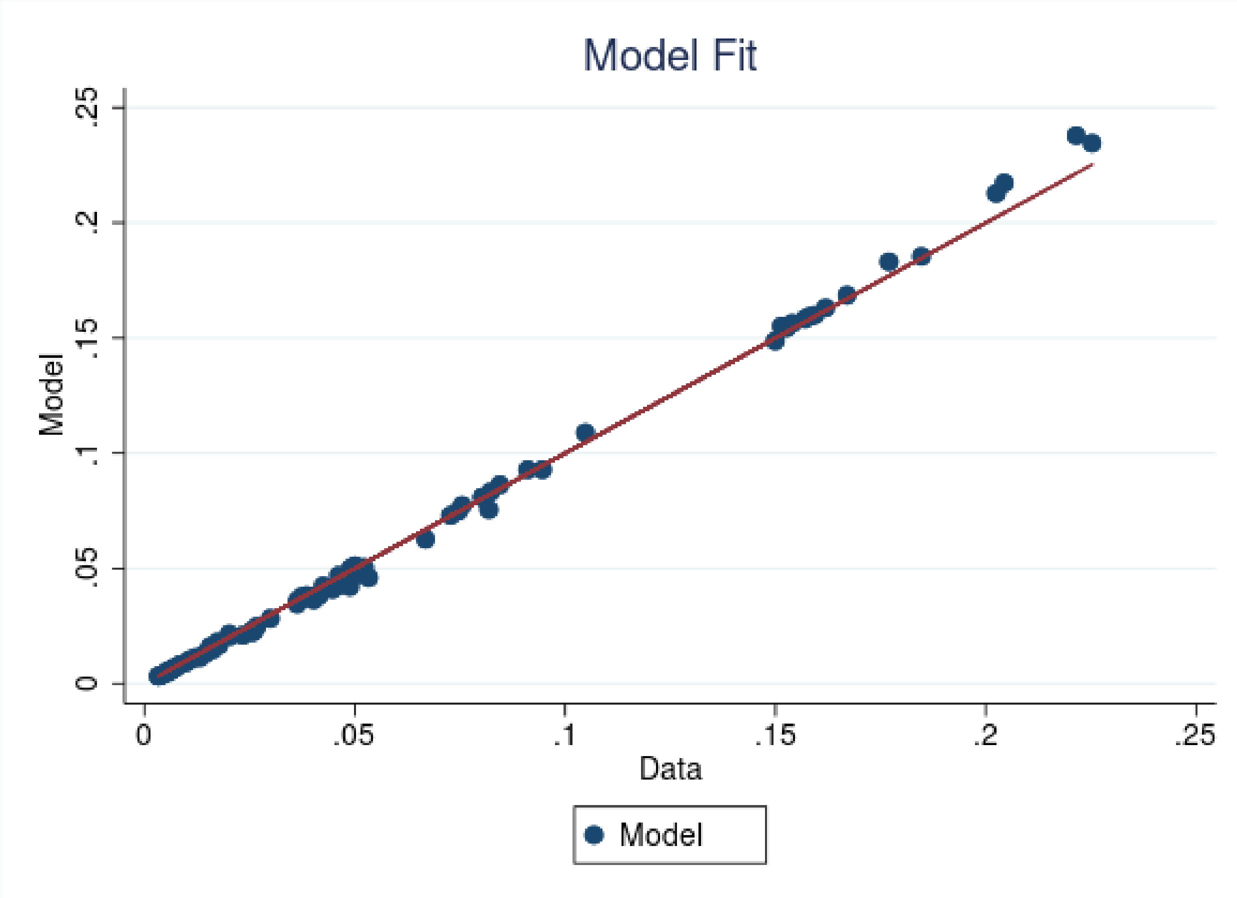

Figure 2: Model Fit

where $\phi(i, o, d)$ is the probability density of importers of type i importing from o to d.

6.2.1 Results

The model fits the data reasonably well. In Figure 2, I plot the predicted market share against the data. The model predicts some of the largest ports should be even larger, but is still very close. In Figure 3, I aggregate the shares of all East Coast ports and plot that against the actual share. The model undershoots the East Coast share for the reason just mentioned: ports like Los Angeles and Long Beach are very large, and the model overshoots them. Meanwhile, most of the smaller ports are on the East Coast.

Table 6 shows the demand coefficients estimated. Recall that the coefficients on land distance, sea distance, and whether or not the port can take larger ships show how those variables affect price, not the consumer's utility directly. For that, we would need to multiply

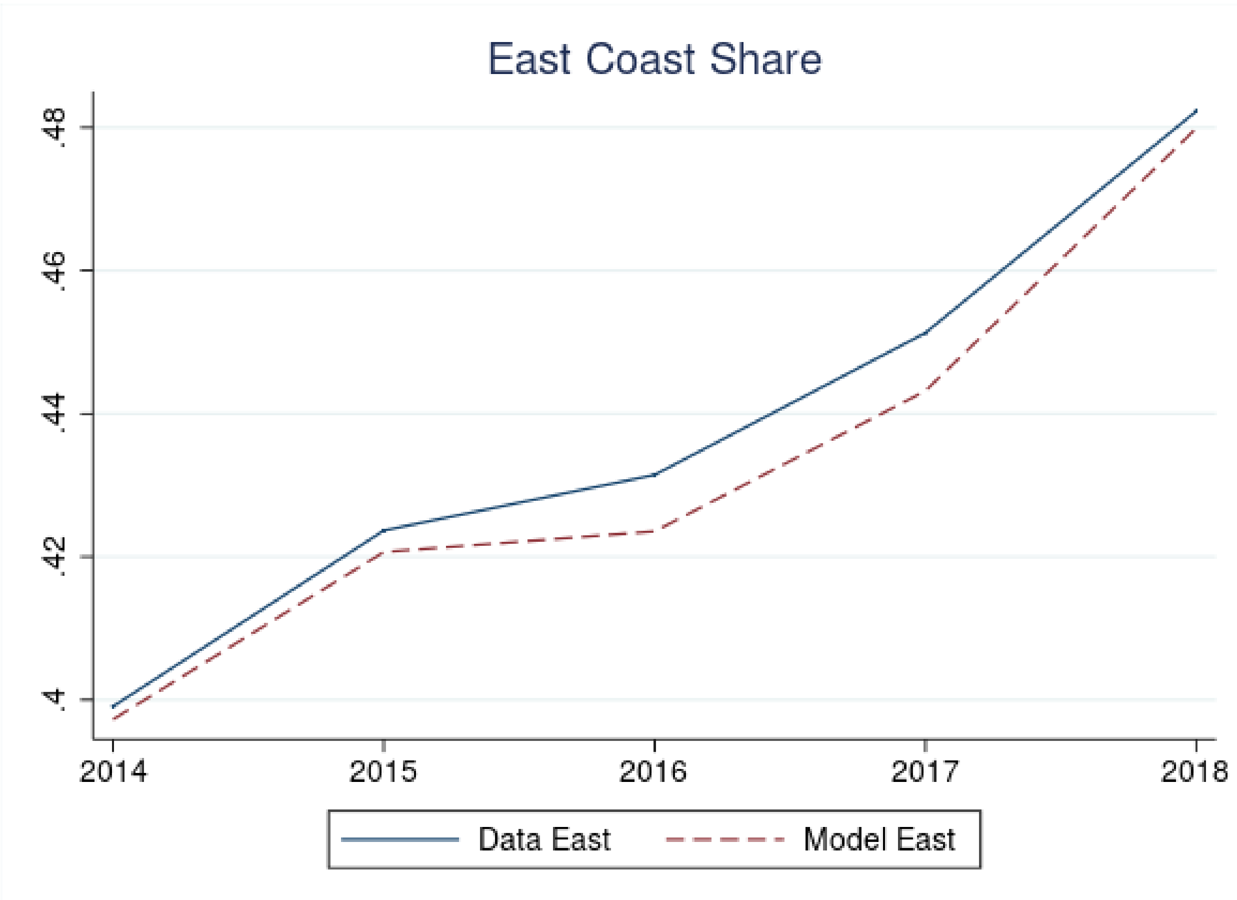

Figure 3: Model Fit

them by the price coefficient. E.g., when a consumer is one kilometer farther, his utility increases by $\alpha \times \beta_{land} \times 1 = -0.0041$. In dollar terms we can look at β_{land} alone, so an additional kilometer is about 5 cents.

It is useful to compare these cost parameters with realistically sized ships. The sea "distance" is scaled down with larger ships to capture economies of scale. Similarly, β_{BSR} is scaled up. For a 5,000 TEU ship, distance is multiplied by around 0.06. Thus the cost of shipping by land is about 63 times as expensive as shipping the same container by sea on a 5,000 TEU ship. For larger vessels the difference is even larger. This fits the pattern in the data of importers closer to East Coast ports choosing to use them as the ship size grows, to minimize the total land distance. At the same time, we see that for the same ship, $\beta_{BSR} \times 5000 \approx 176,400$, many orders of magnitude greater than the cost of travel. Why are there not enormous swings in shares when ports becomes Big Ship Ready, then? In Table 7 I show some of the time-constant quality effects for each port. These are large in magnitude and they are disparate.

α	-0.0782
β_{land}	0.0525
β_{sea}	0.0143
β_{BSR}	-35.28

Table 6: Demand parameters

In Table 8, I present demand elasticities for select ports over this period. I also include the own-elasticity with respect to sea distance. It may be better to think of these elasticities as with respect to the economies of scale of the ship rather than physical distance, which obviously cannot change. For example, plugging in values, a 5% increase in the size of ships would lead to about a 0.9% increase in Norfolk's 2016 market share. These elasticities are small compared to price and especially compared to the elasticity with respect to land. This fits with the findings above that land costs are much higher than sea. Whereas adding or subtracting a few hundred kilometers to the ocean voyage will not have have a large effect

Port	$\bar{\xi}_j$
25th percentile	-7.316
50th percentile	1.999
75th percentile	9.521
Los Angeles	-7.391
Long Beach	-7.739
New York	1.999
Norfolk	-7.086
Houston	9.138

Table 7: Port-level fixed effects

on shares, doing the same for land leads to dramatic shifts.

Port	Price	Sea Distance	Land Distance
25th percentile	-8.512	-0.9832	-12.783
50th percentile	-3.313	-0.8727	-11.071
75th percentile	-2.546	-0.6776	-10.359
New York, 2016	-3.052	-0.8622	-11.335
Norfolk, 2016	-12.623	-0.9352	-10.907
Houston, 2016	-9.053	-1.0166	-9.908

Table 8: Own elasticities for selected ports

6.3 Port Authority Objectives

Recall that ports maximize a weighted average of profits and quantity,

$$[(p_j - mc_j)\, q_j\, (\Omega, a, a_{-j}, p_j, p_{-j})] + \theta q_j\, (\Omega, a, a_{-j}, p_j, p_{-j}) - \mathbb{1}_{a_j}\, (1 - \sigma_j)\, F_j$$

Let $\hat{a}_j$ be the action port j does *not* take. Clearly $W(a_j) - \mathbb{1}_{a_j}(1-\sigma_j) F_j \geq W(\hat{a}_j) - \mathbb{1}_{\hat{a}_j}(1-\sigma_j) F_j$, or, rearranging,

$$\theta_j \geq \frac{(1-\sigma_j) F_j - [(p-c)\, q - (\hat{p} - \hat{c})\, \hat{q}]}{q - \hat{q}} \tag{6}$$

if $a_j = 1$ and $q > \hat{q}$ and

$$\theta_j \leq \frac{(1-\hat{\sigma}_j)\,\hat{F}_j + [(\hat{p}-\hat{c})\,\hat{q} - (p-c)\,q]}{\hat{q}-q} \tag{7}$$

if $a_j = 0$ and $q < \hat{q}$.

I assume that $\theta = \theta_j$, $\forall j$. Then for the nine ports on the East Coast that were not already Big Ship Ready, I have a system of inequalities that allows me to bound θ.

I assume there is a single θ but allow F_j to vary across ports. (I do assume $F_j = \hat{F}_j$, that is, the "hypothetical" cost is the same as if the cost were realized.) Unfortunately, the only ports I see during this period to finish their Big Ship Ready projects are Miami, Houston, and New York & New Jersey. I use the actual costs for their values of F_j. I also see the projected costs of Savannah, Charleston, and Port Everglades. By the time of writing these projects are closer to completion, so the most recent projected costs are likely the actual ones. For the other four ports on the East Coast I do not observe investment costs and thus do not include them in the estimation. (I do observe physical characteristics and could potentially predict costs, but this would require additional modeling.)

For estimation I allow there to be an additional error term on the right hand sides of equations 6 and 7. This encompasses measurement error. We may worry there is an unobserved cost component, say ζ_j. In that case a port will *not* invest if

$$\begin{aligned}
&[(\hat{p}_j-\hat{c}_j)\,\hat{q}_j] + \theta\hat{q}_j - (1-\sigma_j)\,F_j - \zeta_j \leq [(p_j-c_j)\,q_j] + \theta q_j \\
&\Rightarrow \theta + \frac{\zeta_j}{\hat{q}_j - q_j} \leq \frac{(1-\hat{\sigma}_j)\,\hat{F}_j + [(\hat{p}-\hat{c})\,\hat{q} - (p-c)\,q]}{\hat{q}-q}
\end{aligned}$$

and a parallel expression holds if it does invest. Unfortunately there is not a straightforward way to identify both θ and ζ_j without additional assumptions. One potential assumption would be that ζ_j varies across ports but is constant over time and use the panel aspect of the data. I assume

6.3.1 Timing

Though the model abstracts from dynamics, we still need to consider authorities' discounting and expectations to make the payoff W (a flow) and cost F_j (a lump sum possibly amortized over several years) comparable. There are a few possible sources for the discount rate. One is the rate the port authorities face in the financial markets: all of these ports sell millions of dollars worth of bonds in liquid bond markets, so we can look at the rates they face there to get a sense of what the an annualized F_j amounts to. These rates vary between around 3-7% across and within ports, with a mode around 5%. There are also standard numbers used by federal agencies in conducting cost-benefit analysis. The Army Corps of Engineers uses a value based on the average yield of long-term Treasury securitities; in 2016 this was 3.125%. Other agencies use different numbers: the Office of Management and Budget has used 7% since 1992 (Service 2016).

For my baseline, I use 5%. This number is the one most tightly linked to prices the individual ports face, and is also in the middle of the 3.125-7% range. I report other values for robustness results.

6.3.2 Results

Because there are only six moment inequalities, I present them all in Table 9 I include the bounds calculated when ports were making decisions in 2016. The discount rate assumed here is 5%. Using 3.125% or 7% makes very little difference. Miami was the only port to have invested in 2016, New York and Houston were finished one and two years later, respectively.

Port	Lower Bound	Upper Bound
Miami	39.1	-
Houston	-	37.2
Port Everglades	-	46.3
Savannah	-	26.8
Charleston	-	29.6
NY & NJ	-	19.5

Table 9: Bounds for θ in 2016

Though there are only six observations, the upper bounds and single lower bound are all close. The median price-cost margin in 2016 was $17, so the ports appear to value each container two to three times as much as the revenue it brings in.

7 Counterfactuals

In this section, I imagine there is a centralized East Coast port authority. I first show the extreme cases where there is zero investment and when all the ports invest. The first-order results are not surprising: there would be fewer imports to the East if no one invested and more if everyone did. However, in the world with no investment, East Coast imports fall more than West Coast imports rise. Similarly when everyone on the East invests, imports there rise more than West Coast fall. This suggests that even with the Canal expansion, the two coasts are very imperfect substitutes, and that the East Coast is mostly drawing imports from (or losing them to) the outside good.

More interestingly, I find the investment pattern that maximizes the joint surplus of all East Coast ports in 2016. I show the pattern for $\theta = 0$ (port authorities are profit maximizing) and $\theta = 30$, as suggested by the bounds I estimate above.[5] Both scenarios produce results very different from what actually happened. For profit-maximizing ports, the optimal investments would have been the three central Atlantic (Savannah, Charleston, and Wilmington) plus Houston. When port authorities value quantities for their own sake, the optimal is these four plus New York & New Jersey.

Predicting counterfactual market shares requires predicting the counterfactual ship sizes, which depend in part on $q_{o,j}$, the quantity of containers going from a foreign port to a domestic one. This of course depends on the counterfactual demand, which is the quantity I'm trying to simulate. I predict ship sizes with a reduce-form model that predicts size based on year, foreign origin, carrier, and importantly, $q_{o,j}$ and whether the port can take in large ships. I estimate the policy functions for p_j in a similar way, as a reduced-form function of investment and demand. These predicted values are used to estimate market shares, which

5. For the investment costs, I use the actual costs for the ports for which I have data. For the ports with missing data, I simulate three versions: one where they have the same costs as Miami (the lowest), one where they all have the same costs as New York (the highest), and one where they have costs that are the average of the observed. Though the surplus quantities are obviously different, the choice in ports to invest in are the same for all three scenarios.

generate new values for $q_{o,j}$. I use these new values to predict new ship sizes, and repeat the process until the $q_{o,j}$ vectors converge.

For the sake of consistency the "Actual" values in the graphs are the model fitted values, not the raw data.

7.1 No investment

In 2014, all ports on the West Coast and Norfolk on the East Coast were "Big Ship Ready." By the end of my period in mid-2018, three more on the East Coast had been added: Port of New York and New Jersey, Houston, and Miami.[6] In the first counterfactual, I simulate market shares when the centralized authority decides to have no investments, all ports stay as they were in 2014. The results for the East Coast are shown in Figure 4. We can see that even without investment, the East Coast share is higher than it was in 2014. The West Coast share in Figure 5 is higher, but only about 2%. This makes sense when we consider that although few ports on the East could take in the maximum post-Panamax sized vessels, there were some that could vessels just slightly over Panamax. Even without port investment, the Panama Canal expansion had a positive effect on the East's market shares.

7.2 All invest

In this counterfactual, I consider the outcome where all ports on the East Coast become ready for larger vessels by 2017 at the latest. (Ports that were ready by 2017 are still ready earlier.) Figures 6 and 7 show the effects in the East and West, respectively. There is a large increase in 2017, though by 2018 the East Coast share is only about 6% higher than it would be otherwise. The West Coast 2018 share difference is smaller, about 3% below its actual value. Just as in the scenario with less investment, the traffic lost does not all go to the West Coast, in this scenario where there's more investment, not all the traffic gained comes at the expense of the West.

6. Not included in my sample are the Port of Philadelphia, which dredged its main shipping channel to 45 feet in 2017, and Port of Baltimore, which was already 50 feet in 2014. Each of these had 1.80% market share in 2018.

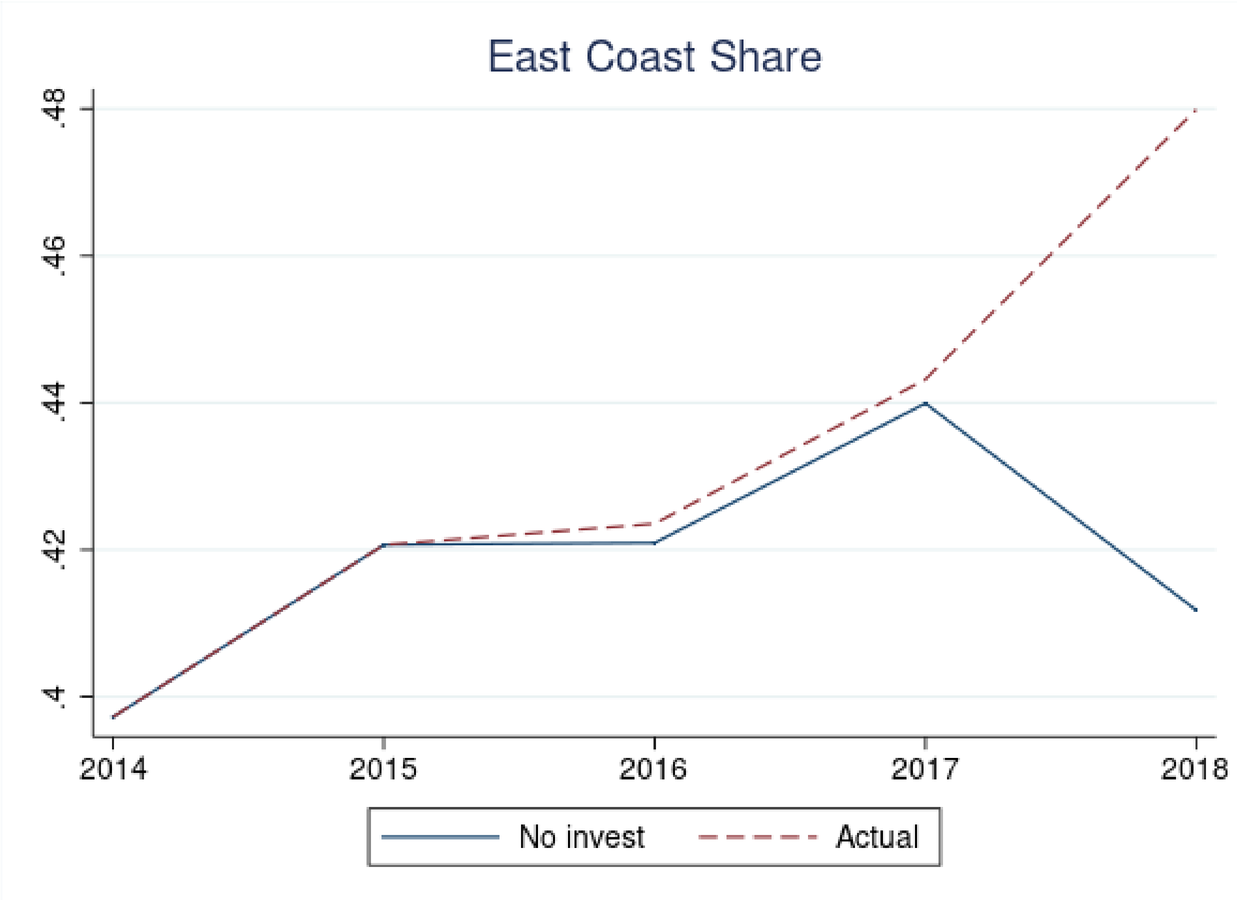

Figure 4: East Coast shares when no East Coast ports invest

7.3 "Optimal" investment

Suppose now that the East Coast ports wish to choose the investment that maximizes their total surplus. From my estimated bounds, 30 is a plausible value for θ, and so for this counterfactual I assume that port authorities value each container as worth \$30, on top of their unit profit. Tto show the importance of considering the non-profit maximizing motives of the authorities, I also show results from $\theta = 0$, that is, when port authorities act as normal profit-maximizing firms. The results are in Table 10.

We see that the optimal investments are much larger than what occurred under the independent authorities, even if they are purely profit-maximizing. There is also an interesting geographic clustering: the optimal investments are all around the "center" of the East Coast plus Houston, which is the farthest port from any other.

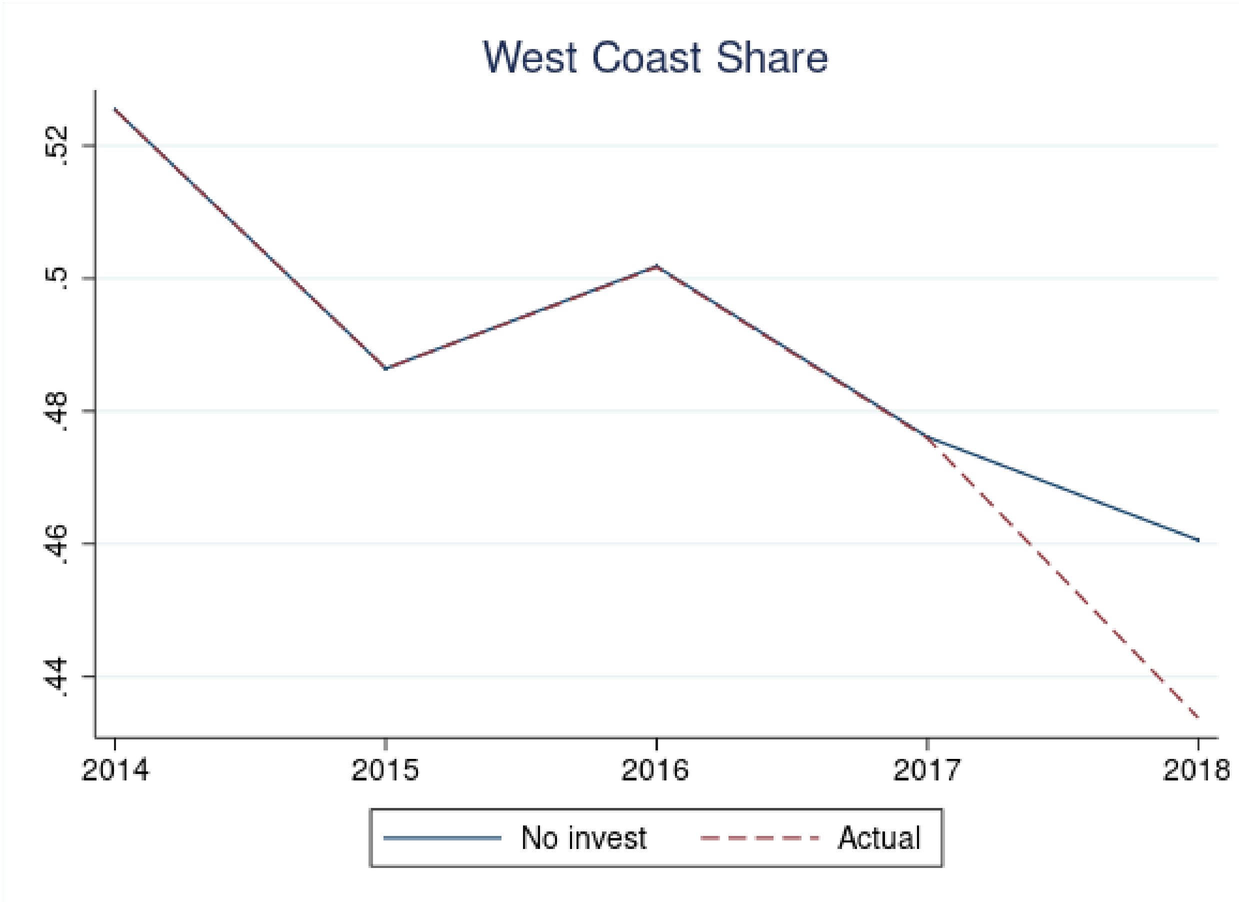

Figure 5: West Coast shares when no East Coast ports invest

There are two additional things to note about the optimal investment, beyond that it is larger: first, investment appears to be complementary with average quality. These ports also have large permanent fixed effects: 23.9, 10.6, 9.9, and 9.1 for Wilmington, Charleston, Savannah, and Houston. New York & New Jersey has lower permanent fixed cost (2.0) but also has lower than average prices. These values are identified largely from them charging relatively high port fees compared to their shares. This comes from the positive externality an choosing one port has on its fellow importers choosing that port: more customers means the carriers can use larger ships, which lowers the average costs for all. Investments cause more importers to choose a given port, and thus it makes sense to invest in the ports that are already of higher quality.

Second, whether or not ports are maximizing profits or something additional makes a significant difference to the predicted optimal investment. The reasoning is intuitive. In-

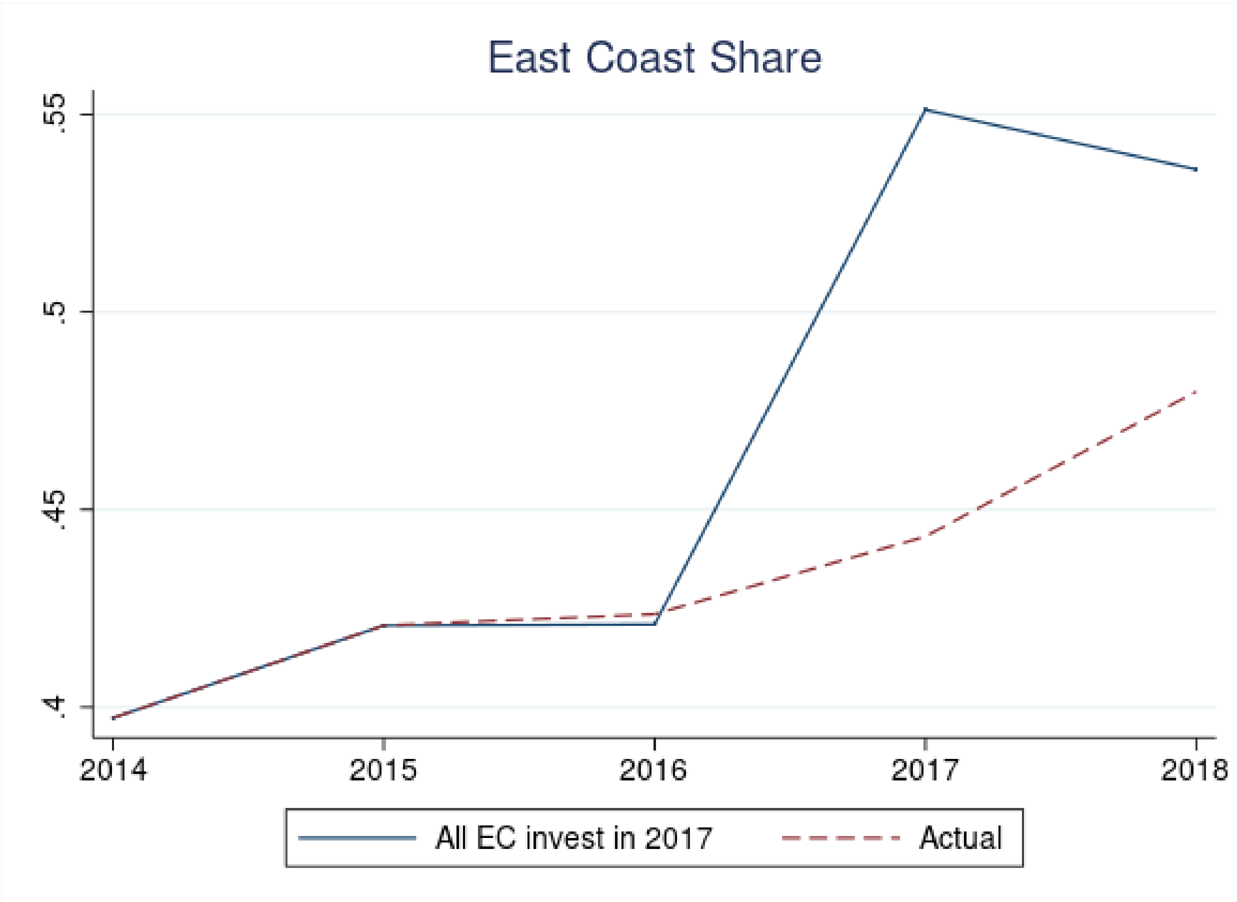

Figure 6: East Coast shares when all East Coast ports invest

vesting in larger ports raises the market share of those ports. The variable cost of unlading containers plus the cost of investment means the investment is not always worthwhile. But if authorities value quantities for their own sake, they are effectively treating the revenue from each container as higher while the costs remain the same and so the incentives to invest are higher.

8 Conclusion

Most infrastructure investment is not done by the US national government but smaller political units. However, the effects of this investment are often national in scope. Though competition can have many beneficial effects, such as increased variety, if these units act strategically there may be negative externalities that could be better internalized by a cen-

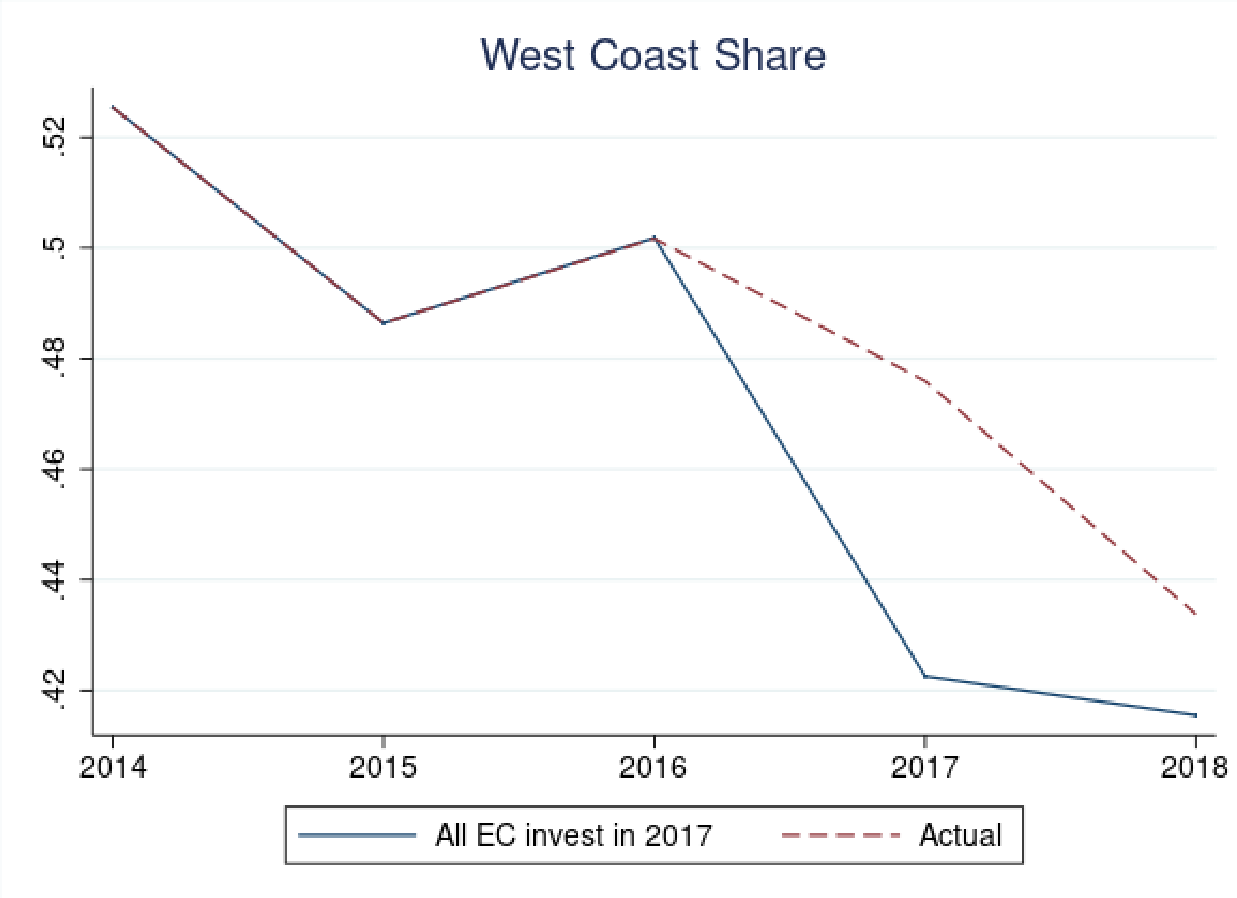

Figure 7: West Coast shares when all East Coast ports invest

tralized authority.

I have looked at the case of container ports in the US in the period leading up to and right after the Panama Canal expanding. The expansion pushed many ports on the East to invest in larger harbors so they could take full advantage of the larger ships. If their business expanded only at the expense of already large ports, the social cost of the investments would not necessarily exceed the benefits. As it turns out, most of the new business came not from the already large West Coast ports but the smaller fringe, ports that show up as my outside good. The total level of investment may be close to optimal. However, when I consider the optimal allocation for the coordinating East Coast port authority, the level of investment is much higher than what actually occurred and that the optimal investment choices are complementary with average quality. Importers value these investments, and their welfare also increases. The costs of coordination in this example are thus outweighed by the benefits

	Ports invested in in 2016
Actual (disaggregated)	Miami
$\theta = 0$	Wilmington, Charleston, Savannah, Houston
$\theta = 30$	New York & New Jersey, Wilmington, Charleston, Savannah, Houston

Table 10: Invesment Decisions Under Single East Coast Authority

for all parties.

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A Economies of scale estimation

A.1 Charter rates

Drewry Insights publishes average daily charter rates for container ships of various sizes. These rates do not include fuel but include labor, insurance, and other operational costs. Most carriers own most of their own fleets, but most also charter at least some ships and so it is reasonable to assume the charter rates cannot vary much from the cost of operating an owned vessel (they certainly cannot be much lower).

I observe 43 observations from 2004 to 2018. The sizes listed are 500, 700, 3,500, 4,250, 5,000, and 8,500 TEU. I estimate

$$\text{log\_charter\_rate}_i = \text{constant} + (1 - \gamma_{charter}) \, \text{log\_TEU}_i + \sum_{t=2004}^{2018} \tau_t \mathbb{1}_{year_i = t} + \varepsilon_i$$

(Jansson and Shneerson 1978) and (Cullinane and Khanna 1999) use an annualized capital cost by regressing the price of newly built ships on size. I use charter rates rather than newbuilds as I do not have the data on costs like crew that these other papers use for my main results. However, I perform a similar regression to compare my number to past ones, and get very similar results. (See Table 5.)

A.2 Fuel costs

In their paper on hull design efficiency, (Faber et al. 2016) use the following relationship between power, speed, and physical dimensions:

$$\log P_{ME} = c \times \log \left(V \times \text{frictional resistance} \right)$$

where c is a constant, V is speed, and "frictional resistance" is a complicated expression that depends on speed, length, draft, and beam. I know that the power required to move the Maersk ship *Emma* is 80,800 kilowatts and I use this to get the correct constant c. For the speed I use the design speed. Finally, the relationship between fuel consumption and power is

$$FC = SFOC \times P_{ME}$$

where FC is fuel consumption and $SFOC$ is the specific fuel consumption of the engine. (Faber et al. 2016) use a value of 190, though (Cullinane and Khanna 1999) use the much lower 125. I use 170. This value is not unimportant as it affects the total fuel usage linearly, but the final results do not change much if I vary it from 100 to 200. (At 100 the final γ is 0.34 rather than 0.28; at 200 it is 0.26.)

A.3 Total cost

To get total costs, I convert the fuel usage to daily fuel usage assuming 24 hours of movement. I take the cost of fuel to be $493, which was the average Brent oil price from 2002 to 2019. (Bunker fuel and crude oil prices are close and move together.) I add the predicted fuel costs to predicted charter costs, take the log, and regress on logged TEU,

$$\log\left(\text{predicted charter}_i + \text{predicted fuel}_i\right) = constant + (1-\gamma)\log TEU + \varepsilon_i$$