Off course? Knot anymore.
Cost Efficiencies and the Panama Canal Expansion

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Abstract

In 2016 the Panama Canal doubled its throughput capacity. Routing choices of East Asian imports to the and within the United States were impacted. I construct a dataset which combines features of international shipping with patterns of U.S. internal trade across several years, varied regions, and multiple products. I quantify and decompose the effects of the Panama Canal Expansion on U.S. East Asian imports using difference-in-difference estimation: total traffic increased by 18% and routes to East Coast ports and through the Panama Canal gained market share at the expense of competing regions and routes. Changes to internal trade are driven by trade-offs between product-specific reductions in per-unit transportation costs and increases in inventory costs. The port of New York accounts for more than 60% of total cost savings post Canal Expansion. Total product transportation cost savings factor out to about 45 billion USD.

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1 Introduction

The 2016 expansion of the Panama Canal was one of the defining events of the shipping industry over the past decade. Coming in at over \$5.4 billion,[1] the Third Set of Locks Project doubled the capacity of the Panama Canal by increasing the number, depth, and width of shipping lanes. As a result, a new class of containerized shipping vessels, dubbed Neopanamax, were introduced into commercial operation. Neopanamax ships can accommodate up to 14,000 TEUs (twenty-foot equivalent containerize unit), compared to older ships with a capacity of 5,000 TEUs. This pronounced expansion in capacity has generated strong predictions within the supply chain management industry: up to 10% of containerized shipping from East Asia to American markets could shift from West Coast ports to East Coast ports by the year 2020. Bratton et al. (2015)

Before the 2016 expansion, the majority of East Asian imports were transported to East Coast and Midwest markets via the Suez Canal or through an inter-modal transport network starting at West Coast ports. After 2016, East Coast ports were uniquely positioned to contest West Coast market share of East Asian imports to East Coast and Midwest markets *provided they had the requisite infrastructure.* As of 2016, only a handful of East Coast ports could receive Neopanamax containerized shipping and making East Coast ports Neopanamax ready has proven to be considerable undertaking: for instance, the port of Savannah Georgia committed an initial \$723 million to deepen its harbor [2] whereas the Port Authority of New York-New Jersey invested \$1.3- 1.7 billion to raise the Bayconne Bridge to clear Neopanamax ships.[3]

The goal of this paper is to analyze how international shipping patterns to and throughout the United States were impacted as a result of the 2016 Expansion. I construct a high-resolution dataset that allows me to connect containerized shipping records to the flow of internationally sourced (by ship) commodities to and within the United States across various transportation modes and years.

I perform two empirical exercises to assess the full impact of the Panama Canal expansion within the United States. First, I provide preliminary evidence of changed *routing choices* as result of the 2016 expansion through difference-in-difference modeling: East Asian import traffic (absolutely) increased by 15% to East Coast ports after the Panama Canal Expansion, whereas West and Gulf ports lost (relative to East Cost ports) between 22 and 16 percent of their respective traffic. Second, I run a simple accounting exercise to incorporate location and product specific dimensions to estimate cost savings implied by the use of more efficient container ships at East ports. On the whole, approximately 45.32 bil USD is saved as a result of the cost-saving efficiencies made possible by the Canal's expansion. Cost savings per affected US sub-market (either a metropolitan region and/or some share of a US state) average about 3.5 percent points and are (absolutely and relatively) greater for richer and more accessible regions.

[1] See: `https://tinyurl.com/t2rvswy`.
[2] See: `https://tinyurl.com/rsqwmmp`.
[3] See `https://tinyurl.com/r79wk9e`.

This paper is closely related to Heiland et al. (2019) and Park and Park (2016). Heiland et al. (2019) use AIS satellite data to construct a global maritime shipping network and use difference-in-difference techniques to estimate general equilibrium impacts of the 2016 expansion. Relative to Heiland et al. (2019), my paper provides necessary insight into *why* shipping patterns ought to change post the Panama Canal expansion: namely, shippers will choose a combination of product-sensitive transportation modes to ship goods to different markets to maximize profits across an entire shipment. Park and Park (2016) model internal freight flows, but are limited to pre-expansion data; moreover, their paper does not have the capacity to capture changes to international shipping routes.

2 Background

2.1 Scale Economies in Containerized Shipping

In 2015, Post-Panamax (elsewhere Neo-Panamax) ships represented 16 percent of the world's container ships, yet were responsible for nearly 45 percent of all container cargo; industry projections suggest that by 2030, Neo-Panamax ships will make up more than two thirds of all container traffic. Bratton et al. (2015).

Containerized shipping is an industry characterized by economies of scale. Cullinane and Khanna (1999) find that average container shipping costs (per TEU) decrease as both *shipping volumes* (TEUs) and *voyage length* increase.

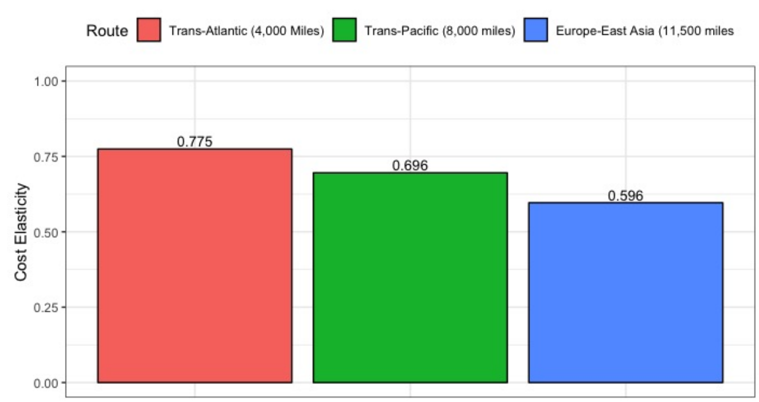


Figure 1: Containerized Shipping Economies of Scale

Source: Total shipping cost per TEUs were taken form the "As modelled" column of Table 3 (Cullinane and Khanna, 1999, p. 202).

Notes: Cost elasticity is estimated as $\hat{\beta}_1^r$ from the regression $\ln(COST_i^r) = \beta_0^r + \beta_1^r \ln(TEU_i^r) + \varepsilon_i^r$ for each route r. All estimates are statistically significant at the 1 percent level.

Table 1 gives an ex-ante forecast of cost reductions accrued through larger ships/economies of scale by route.

Route	**6,000 TEU Vessel**	**8,000 TEU Vessel**
Asia- U.S. East Coast	8%	16%
Asia-U.S. West Coast	8%	17%
Asia-U.S. East Coast through Suez	7%	17%

Table 1: TEU Cost Savings
with Post Panamax Ships relative to 4,000 TEU Panamax Vessel Service
Source: (PCA, 2006, p. 31)

The main focus of this paper is on East Asian imports to East Coast ports and markets easily accessed from the East Coast. Prior to the 2016 Expansion, the majority of East Asian imports arrived at West Coast ports: two thirds of 2014 East Asian container traffic was routed through the West Coast. The remainder of 2014 imports were routed to the East Coast through the Panama Canal (one fifth of total imports and roughly 60 percent of East Coast imports) and the Suez Canal (14 percent of total imports and approximately 40 percent of East Coast imports) Bratton et al. (2015)

2.2 Sources of Competition to the Panama Canal

2.2.1 American Intermodal Transportation Network

The largest source of competition to Panama Canal traffic prior to 2016 came from the US intermodal transportation network. Cargo arrives at West Coast ports—namely Lost Angeles/Long Beach, Oakland, and Seattle/Tacoma—via container ship and is then transferred to either freight rail and/or truck. Prior to the 2016 expansion, the intermodal system was attractive routing option for at least two reasons: NeoPanamax ships could be accommodated by West Coast ports and total transit time to all American markets was much shorter (see Figure 16). When the Panama Canal Expansion was announced in 2006, the intermodal system commanded a 61 percent market share of East Asian imports.

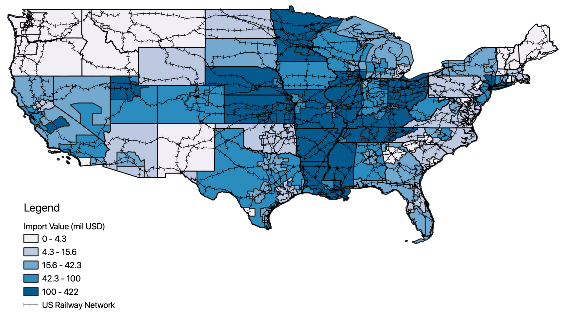


Figure 2: East Asian Imports and West Coast Rail

Notes: Data are from the 2015 version of Freight Analysis Framework (FAF4) Database. FAF4 regions are filled in based on the total value (million USD) of imports from East Asia that were (i) shipped by boat to ports in Los Angeles (LA); and (ii) then shipped from LA to elsewhere in the US via freight rail.

Patterns of intermodal shipping help to map out the importance of realigning international shipping routes. Figure 2 illustrates where East Asian imports end up after they arrive by ship at the ports of Los Angeles/Long Beach and are then shipped off via freight rail. Aggregating total import values by US Census region,[4] the MidWest is the top destination for freight trains leaving Los Angeles. In 2015, the total value of East Asian imports arriving at Los Angeles/Long Beach that were then shipped by freight rail was approximately 7.99 billion (USD). Midwestern states were the ultimate destination for 3.34 billion (42 percent) of those imports, followed by Southern states (2.68 billion, 34 percent), other Western states (1.01 billion), and Northeastern states (0.95 billion).

2.2.2 Suez Canal

Prior to the 2016 Expansion, the Suez Canal route was the most cost-effective option when shipping from South and Southeast Asia to East Coast ports.[5] This competitive edge came both from shorter transit times and the Suez Canal's capacity to service Post-Panamax vessels.(Salin, 2010, p.6) These two advantages were also present when for East Asian imports to East Coast ports, although to a lesser degree. Prior to the expansion, East Asian imports could be routed either Pacific Coast-Intermdoal System or the Suez Canal. To the extent that U.S. intermodal system was hampered by congestion, strikes, and escalating cost, shippers often opted for the Suez Canal route.

[4]See Table 20 and `https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf`.

[5]South Asia includes: Afghanistan, Bangladesh, Bhutan, India, Nepal, Maldives, Pakistan, Sri Lanka, Pakistan, Myamnar, and Iran. Southeast Asia includes: Brunei, Cambodia, Indoensia, Laos, Malaysia, Phillipines, Singapore, Thailand, and Vietnam.

Table 2 gives a quick and ex-ante glance at the capacity differences between the Suez and Panama Canal before and after the 2016 expansion. The Panama-Panamax column serves a pre-expansion capacity benchmark. Based on 2006 data, the Panama Canal Authority estimated that the average round trip from East Asian ports to East Coast ports through the Panama Canal (Suez Canal) took 56 days (77 days), which implies an annual shipping frequency of 6.5 (4.7) trips per year. (PCA, 2006, p.21) The minimum number of vessels need to service the Panama Canal (Suez Canal) route is 8 (11). Since Post-Panamax vessels could pass through the Suez Canal, a shipper's annual capacity through the Suez Canal came out to 37,600 TEUs relative to the Panama Canal's 31,200 TEUs. Under the assumption that transit times remain the same for both routes after the 2016 expansion,[6] the increase in vessel size should make the Panama Canal route far more attractive. A smaller minimum fleet sized with an enlarged capacity combined with shorter travel times (i.e. corresponding higher annual trip frequency) had the predicted effect of making annual capacity per shipper approximately 38 percent higher through the Panama Canal compared to the Suez Canal.

Variable/Vessel Type	**Panama**		**Suez**
	Panamax	*Post-Panamax*	*Post-Panamax*
Vessels	8	8	11
Capacity per vessel (TEUs)	4,800	8,000	8,000
Trips per year	6.5	6.5	4.7
Shipper annual capacity (TEUs)	31,200	52,000	37,600
Canal annual capacity (TEUs)	249,600	416,000	413,600
Shipper annual capacity relative to Suez	0.8298	1.383	1

Table 2: Suez Canal Productivity Differences (East Asian Imports to East Cost)
Source: (PCA, 2006, p.20-21)

[6] Vessel speed is a function of world demand of shipping services. Sterling (2019) reports that the elasticity of transit speed with respect to the ratio of charter rates to bunker fuel prices is 0.2. In concept, there should the expansion of the Panama Canal should have a differential impact on charter rates for services through the Suez Canal and the Panama Canal; thus relative differences in transit time may well change. Regardless, based on shipping data from BlueWater reporting, shipments to the East Coast through the Suez Canal on average traverse 25 percent more (nautical) miles relative to the Panama Canal route.

2.3 Panama Canal Expansion Specs

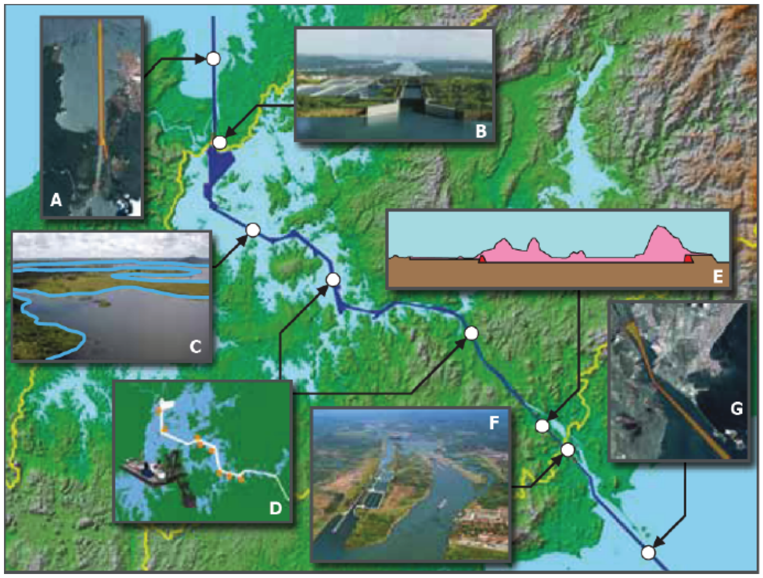


Figure 3: Main Features of Canal Expansion
Legend: (A) Atlantic entrance deepening and widening. (B) Atlantic Post Panamax Locks. (C) Increasing Gatun Lake's maximum operation level. (D) Deepening and widening of Gatun Lake and Culebra Cut navigational channels. (E) Post-Panamax locks Pacific access channel. (F) Pacific Post-Panamax locks. (G) Pacific entrance deepening and widening.
Source: (DOTMARAD, 2013, p. 4)

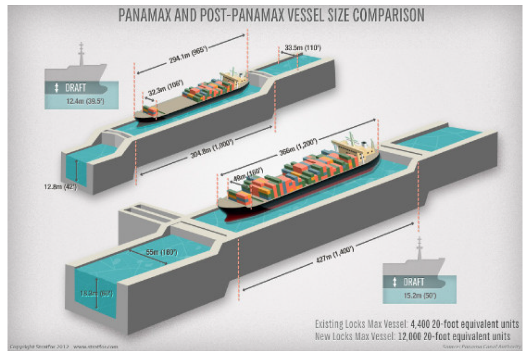
The various construction projects in Figure 3 build to one outcome: a doubling of maximum cargo-carrying capacity.[7] All told, the expansion of the Canal required 5.3 billion and 194 million cubic feet of materials and concrete, respectively. (Zupanovic, Grbić and Barić, 2019, p.538) This result was achieved through the construction of:

i) **A third traffic lane and a new set of locks**. The new lock system includes a set of locks at the Canal's Atlantic/Pacific entrances in addition improving on the Gatun Lake lock set. Pre-expansion locks are 1,000 feet long, 110 feet wide, and 42 feet deep, thus capping vessel transit with over 5,000 TEUs. Post-expansion locks instead are 1,400 feet long, 180 feet wide, and 60 feet deep. New locks will permit passage of container ships with a nominal carrying capacity of 13,000 TEUs (DOTMARAD, 2013, p. 5); and,

[7]The Panama Canal Authority (PCA hereafter) measures throughput volume through use of the Panama Canal Universal Measurement System (PCUMS hereafter). A PCUMS ton is equivalent about 7.6 percent of a single TEU container. Prior to expansion, the Canal's annual capacity held at 300 million PCUMS (2011 estimate); the PCA anticipated that the Canal's expansion would double *this* capacity.

ii) **Deeper and wider channels**. Both the Culebra Cut and Gatun Lake (two-directional simultaneous transit) channels were deepened by four (4) feet. What is more, the elevation of Gatun Lake was raised from 87.5 to 89 feet to accommodate the new lock system's expanded water needs without limiting local water usage. (DOTMARAD, 2013, p. 5) The deepening of the lake added roughly 7.06 billion cubic feet worth of water. (Zupanovic, Grbić and Barić, 2019, p.538)

(a) Third Set Lock Construction
Source: Fierman (2016)



(b) Lock and Ship Size Change
Source: (Zupanovic, Grbić and Barić, 2019, p.538)

Figure 4: Locks

3 Data Description

3.1 BlueWater Reporting

Container shipping data come from BlueWater Reporting, which maintains a database of ocean sailing schedules, capacity, and service information. I use BlueWater's data on North American imports. The data feature 359 distinct ports, across 109 countries over the 2014-2017 period (August-October of each year). There are a total of 96,317 unique voyages across the dataset. As originally presented, a voyage is defined by a *rotation schedule*, or a sequence of port stops. Consider a voyage with the following rotation schedule:

$$A \rightarrow B \rightarrow C \rightarrow D \rightarrow B \rightarrow F \tag{1}$$

BlueWater Data also report the number of days elapsed since the beginning of the voyage (e.g. 10 days from port A to port C), the allocated weekly capacity along the voyage (measured in TEUs), and the origin/destination ports. Generally speaking, the specified origin/destination ports are different from the beginning/terminal elements of the rotation schedule. For example, though A

and F are the start and end, respectively, of rotation schedule (1), ports C and B could be the listed origin and destination ports, respectively. Thus, I define a *voyage* as the sequence ports book-ended by the specified origin/destination ports.

Features of a typical voyage include:[8]

- **time**: Number of *scheduled* travel days between ports.
- **type**: For a voyage sequence with more than two legs, a trip is broken up into a starting (S), middle (M), and terminal (T) leg. Direct trips are coded as well (D).
- **WeeklyCapacity**: TEU measurement.
- **pan**: Dummy to indicate whether a voyage used the Panama Canal.
- **lon_change/lat_change**: Gives the cardinal direction of change per voyage leg.
- **suez**: Dummy to indicate whether a voyage used the Suez Canal.

The data as presented in Table 17 are ill-suited to use in regression analysis because of the data's (now) fragmentary structure. The trade flows between the origin and destination port are no longer directly observable. Consider voyage V1 given by port sequence: $A \rightarrow B \rightarrow C$. Using what I refer to as the *voyage format*, as per Table 3a, it is difficult to (directly) observe the total distance traveled/total time elapsed between ports A and C. For this reason, I **define a trip** as a subsequence of voyage port combinations. Thus, a voyage with n ports will have $n-1$ trips and a total of ${}_n\mathrm{C}_2 = n!/\big(2(n-2)!\big)$ trip segments. Table 3b shows how BlueWater *voyage format* data are recast in the *trip format*.

[8] See Table 17

Origin Port	Destination Port	Time	Distance	Capacity	Voyage ID
A	B	10 days	20 miles	200 TEU(s)	V1
B	C	5	10	200	V1

(a) Voyage Format

Origin Port	Destination Port	Time	Distance	Capacity	Trip
A	B	10 days	20 miles	200 TEU(s)	V1.a1
A	C	15	30	200	V1.a2
B	C	5	10	200	V1.b1

(b) Trip Format

Table 3: BlueWater Reporting Data Formats
Notes: Voyage $i \in \mathbb{N}$ is denoted by `Voyage ID` as Vi. `Trip`s are identified by the `Voyage ID` followed by a period and lower case letter. `Trip Segment` ids follow a `Trip`'s lower case letter.

I record if a trip segment uses the Panama and/or Suez Canal if: the information appears directly in the shipping schedule (e.g. Balboa Panama and/or Port Said Egypt are listed in the rotation); or if the shortest path between ports uses either canal and canal information is absent from the schedule (e.g. Origin Port is Miami and Destination Port is LA and no Panama stops are reported).

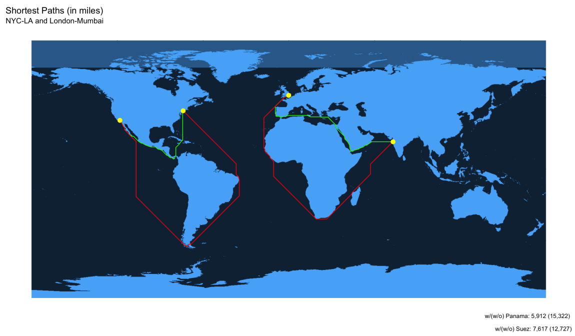
3.2 Nautical Distances

I geo-code each of the 359 ports and then compute the shortest nautical distance between observed port pairs.[9] The data have 1,670 unique port pairs across all four years. I record whether a shortest (sea)distance for each port pair uses: the Panama Canal, the Suez Canal, or no canal. 118 (7 percent) of port pairs use the Panama Canal, 30 pairs (2 percent) use the Suez Canal, and 1,522 pairs (91 percent) use neither canal.

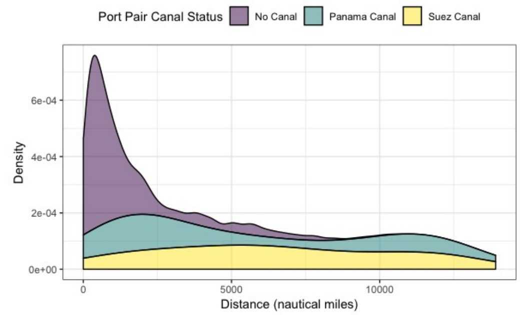
Figure 5 gives a distributional sense of voyage mileage across pairs. In general,voyages through

[9]Nautical distance provides fewer complications relative to time at sea. As indicated by Sterling (2019), vessel speed is sensitive to changes to the ratio in the demand for maritime shipping relative to the price of fuel. Feyrer (2009) computes shortest nautical distance in terms of using estimated shipping time. Their estimated shipping time assumes an average vessel speed of 20 knots and incorporates ocean-current velocity. I replicate this approach by using average surface ocean-current velocity data for the summer of 2015 complied by the *Asia-Pacific Research Center* (see: `http://apdrc.soest.hawaii.edu/projects/argo/`). In general, the speed (i.e. the magnitude) of ocean currents appears to be negligible, with less than 2 percent of currents having speeds of greater than 1 knot. See the Appendix for further discussion.

the Panama Canal are shorter mileage-wise relative to those through the Suez Canal. Figure 5a depicts what the shortest sea routes between New York and Los Angeles (London and Mumbai) look like using and not using the Panama Canal (Suez Canal).



(a) Shortest Sea Path with(out) Canals
Source: Method used comes from (Besley, Fetzer and Mueller, 2015, p. 37)



(b) Shortest (Nautical) Distance Distribution
Source: BlueWater Reporting and author's calculations.

Figure 5: Nautical Distance Results

3.3 FAF4 US Internal Flows

I use FAF4 data to capture (i) US import of goods by regions; and (ii) the internal flow of goods within the US. FAF4 stands for Freight Analysis Framework (version 4) and was created by the *Center for Transportation Analysis* Oak Ridge National Laboratory (Oak Ridge hereafter). Beginning with 2012 Commodity Flow Survey Data, Oak Ridge maintains a database combining internal trade flows (sourced from the Bureau of Transportation Statistics, the the Federal Highway Administration, and the Department of Transportation) with foreign trade flows (sourced from the US Census Bureau).

The main advantage of FAF4 data relative to Commodity Flow survey is increased reporting frequency. FAF4 data covers 2012-2018 internal trade flows within the US and additionally has 5 year interval forecasts across 2020-2045. In contrast, the Commodity Flow Survey is released every 5 year (e.g. years ending in "2" or "7"). This increased reporting frequency does come at the cost of coarser data in terms of product and geographic characteristics.

1. **Product Characteristics**: Foreign imports are classified according to Standard Classification of Transported Goods (SCTG) codes at the two digit level for a total of 42 SCTG groupings.[10] At this two digit level, SCTG codes are directly comparable to Standard In-

[10]See Table 19 for more.

dustrial Classification (SIC) and North American Industrial Classification System (NAICS) industry classification codes BTS (2017).

2. **Geographies**

   (a) *Foreign Regions*: FAF4 aggregates and reports US trade flows from the following regions: (1)Canada; (2)Mexico; (3)Rest of Americas (including Puerto Rico and U.S. Virgin Islands); (4) Europe; (5) Africa; (6) Southern, Central, and Western Asia; (7) Eastern Asia; and, (8) South-Eastern Asia and Oceania.

   (b) *Domestic Regions*: FAF4 partitions the United States into 129 zones. FAF4 domestic region boundaries are given in a shapefile which also lists the constituent counties that makeup the FAF4 domestic region. FAF4 domestic region closely (if not identically) map onto Commodity Flow Survey (CFS) zones. I use the centroid of each FAF4 zone as the approximate location of each FAF4 domestic region.

A typical observation of FAF4 import data contains the foreign region of origin, the FAF4 domestic zone of entry, the FAF4 domestic zone of delivery, the international transportation mode (restricted to maritime shipping), the intra-national transportation mode (restricted to freight truck and rail), the two digit SCTG code, the year of delivery, and import flows measured in weight, value, and ton-miles.

3.4 US Transport Network Data

I construct a network model representation of both the US highway and freight rail network from shapefiles found in the Natural Earth Collection. (2020) Both infrastructure shapefiles come from the CEC North America Environmental Atlas with no attributes. Each shapefile is presented at a 1:10m scale and has only 1 scale rank class. I clean each shapefile in QGIS and incorporate the location of all FAF4 domestic regions. I use QGIS's implementation of Dijkstra's algorithm to compute the length of the shortest path between all FAF4 zone pairs ($(129 \times 128)/2 = 8,256$ unique pairs) along each transportation network.
QGIS's shortest distance calculations, particularly road distances, match other distance calculations fairly well. By way of an anecdote, using New York, NY (FAF4 region) as a starting point, the estimated road distance to Albany, NY (FAF4 region) is 161 miles (to Google Map's 163 miles) and to San Jose,CA (FAF4 region) is 2,861 miles (to Google Map's 2,935 miles).

3.5 FAF4 Regional Characteristics

All data come from the Bureau of Economic Analysis (BEA). Each variable is reported at the county level, and since FAF4 regions comprised of counties, I aggregate over all counties per FAF4 per year to get FAF4 measures of the following variables: GDP, population (not households), personal income,[11] and per-capita income.

3.6 Bringing the data together

Figures 14 and 15 showcase the results of merging of (i) BlueWater (US) ports; (ii) FAF4 regions; and (iii) infrastructure networks. Each US port is mapped into the closest FAF4 region. Since all FAF4 regions are connected through either infrastructure network, and ports are connected to each through the maritime shipping network, I construct the distance minimizing path between foreign ports of origin to final destination.

Figure 6 is a snapshot of the assembled shipping, transport, spatial-economic data used to represent the route(s) of East Asian imports to throughout the United States. The map features 2015 data on the following:

- **BlueWater Ports**: The 20 US ports that received imports from East Asian ports are scaled in proportion to aggregate (East Asian) imports.
- **FAF4 Regions**: Each of the 129 regions is defined by two features:
  - *Per-capita Income*: The centroid of each FAF4 is scaled according per-capita income (from the BEA).
  - *Transit Time*: Each FAF4 region is colored according to how long it takes to ship goods from East Asia, which first arrive at Los Angeles (LA), and are then shipped via freight truck. The median (2015) transit time observed in BlueWater shipments for vessels starting in East Asia and ending up in LA is 15 days. Finally, I assume an average highway speed of 55mph (for this map only). The 15 day maritime shipping time summed with truck shipping time provides an estimated total time of delivery.
- **Shipping Networks**: The red line shows the distance minimizing route between LA and NYC via the US highway system; the faint purple lines makeup the rest of the US highway system. Finally, the pink (green) line represents the shortest sailing path from Shanghai to LA (NYC) through the Pacific Ocean (Panama Canal). I estimate that the direct route from Shanghai to LA is 6884.32 miles; this compares to 12,690.35 miles from Shanghai to NYC through the Panama Canal.

[11] Consists of the income that persons receive in return for their provision of labor, land, and capital used in current production as well as other income, such as personal current transfer receipts. In the state and local personal income accounts the personal income of an area represents the income received by or on behalf of the persons residing in that area. It is calculated as the sum of wages and salaries, supplements to wages and salaries, proprietors' income with inventory valuation (IVA) and capital consumption adjustments (CCAdj), rental income of persons with capital consumption adjustment (CCAdj), personal dividend income, personal interest income, and personal current transfer receipts, less contributions for government social insurance plus the adjustment for residence.

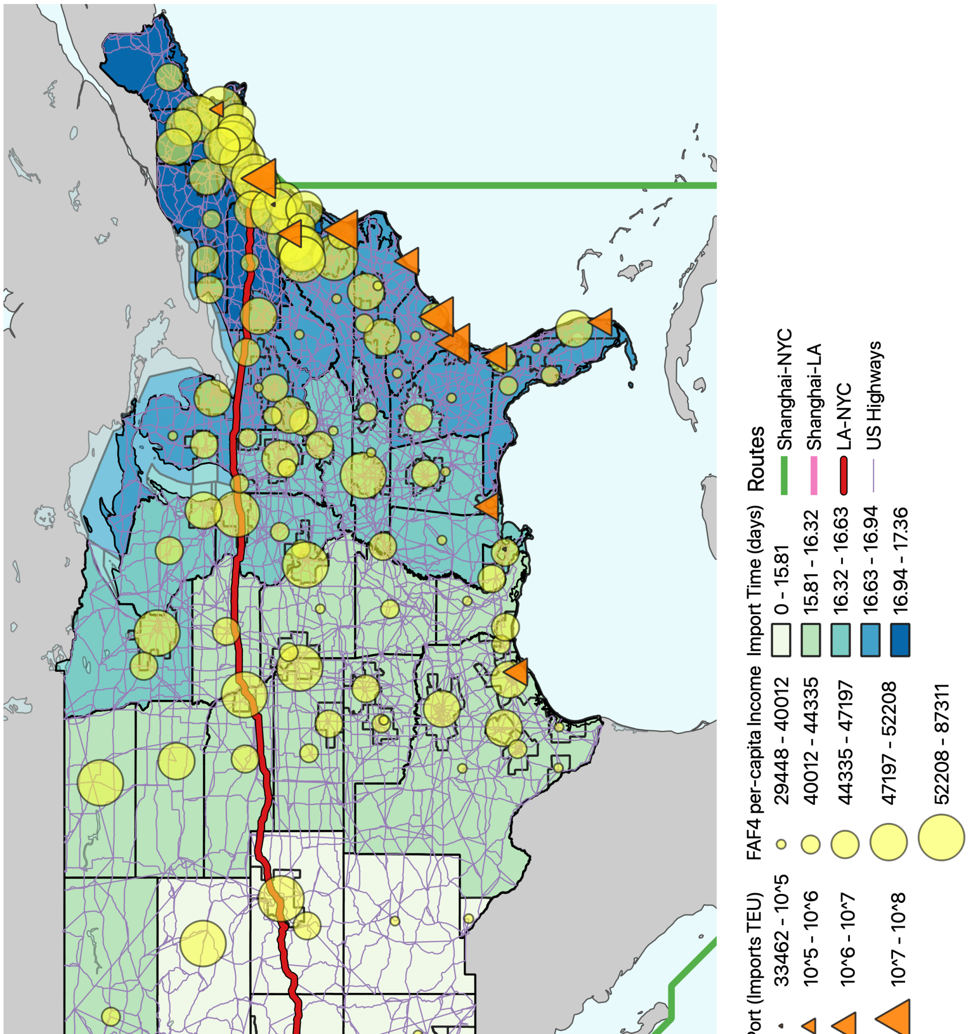


Figure 6: Combined Data Map

4 Changes to Maritime Shipping Patterns

4.1 Preliminary Evidence of Change

4.1.1 Coastal Trends

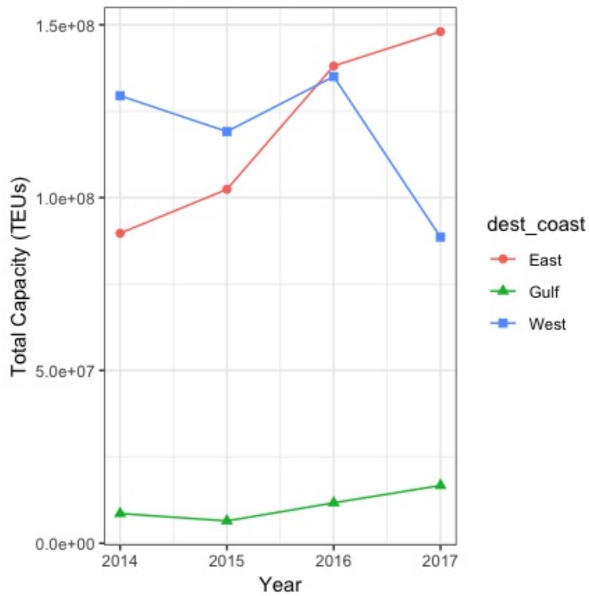


Figure 7: Total Capacity by Coast

Total imports from East Asian ports to American ports increased by approximately 18 percent in the two years post the Canal's expansion relative to the two years prior. Figure 7 illustrates that the growth was primarily driven by increased East Coast Traffic and that total traffic increased notwithstanding decreases to West Coast traffic.

The next Figures decompose trends presented by 7 into trade shares and route volumes. Figure 8 depicts changing shares of East Asian import capacity allocation, with a sizeable jump in Panama Canal traffic post 2016. Figure 9 decomposes route traffic by destination coast. Note the:

- Increase in East Coast traffic through Panama post 2016;
- Decrease in East Coast traffic from the Suez Canal; and,
- Decrease in Pacific Ocean routed shipments to West Coast ports (which is the same thing as saying that West Coast imports fell since West Coast ports only receive goods through the Pacific Ocean).

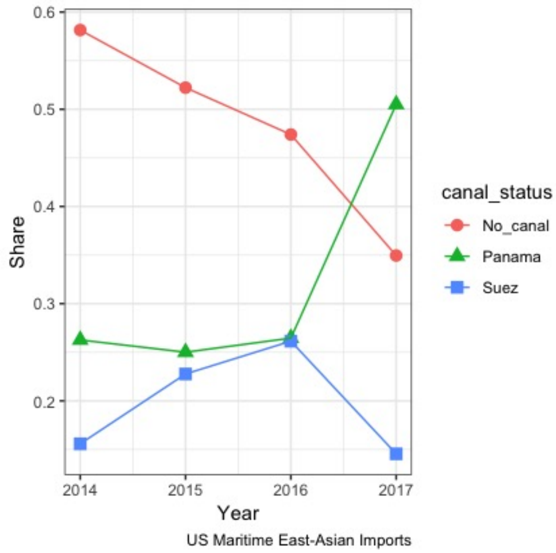


Figure 8: Route Share

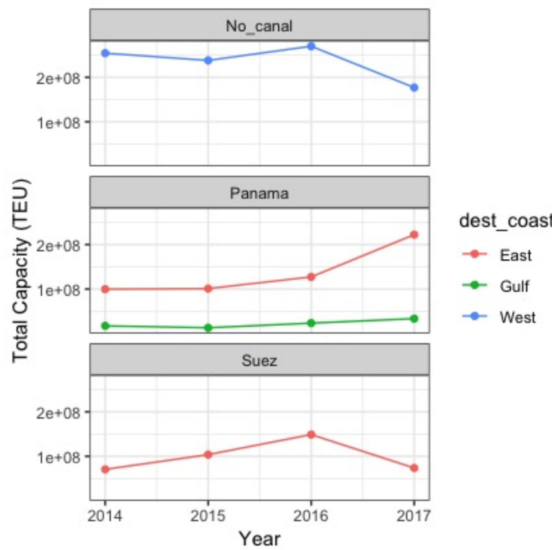


Figure 9: Route and Coast

4.1.2 Dif-in-Dif Model

I perform a difference in difference analysis to model the differential impacts of the Panama Canal Expansion according to:

$$\ln\Big(X_{ijt}\Big) = \beta_0 + \beta_1 Post_t + \beta_2 V_{ij} + \beta_3 \Big(Post_t \times V_{ij}\Big) + \varepsilon_{ijt} \tag{2}$$

where X_{ijt} is allocated capacity (TEU) exported from location i to j at time $t \in \{2014, \ldots, 2017\}$, $Post_t$ is a dummy variable equal to unity if t is after June 2016 and zero otherwise, and V_{ij} is a set of interaction variables. These interaction variables consist of:

- *Destination Coast*: US ports of destination (j) are grouped by coast: West Coast, the Gulf Coast, and the East Coast. The East Coast is used as the reference level.
- *Canal Usage*: Routes between (ij) are grouped according to which canal was used during a trip. Groupings consist of: the Panama Canal, the Suez Canal, and No Canal (e.g. direct Pacific Ocean routes). Panama Canal is used as the reference level.

I restrict imports flows from i to East Asian ports (40 total) found in the following geographies: China, Hong Kong, Japan, South Korea, and Taiwan. Likewise, BlueWater lists 27 US ports as importers j of East Asian shipments.

	Model 1	Model 2	Model 3	Model 4
(Intercept)	8.1280***		7.8561***	
	(0.0061)		(0.0068)	
Gulf	−0.2747***	−0.2518***		
	(0.0192)	(0.0136)		
West	0.0997***	0.4187***		
	(0.0087)	(0.0063)		
$Post_t$	0.3148***	0.3108***	0.3621***	0.3699***
	(0.0084)	(0.0059)	(0.0092)	(0.0065)
Gulf $\times Post_t$	−0.1730***	−0.3157***		
	(0.0244)	(0.0170)		
West$\times Post_t$	−0.2415***	−0.2754***		
	(0.0125)	(0.0088)		
No Canal			0.3660***	0.5953***
			(0.0091)	(0.0066)
Suez Canal			0.8922***	0.5746***
			(0.0129)	(0.0098)
No Canal $\times Post_t$			−0.2830***	−0.3256***
			(0.0129)	(0.0092)
Suez Canal $\times Post_t$			−0.3441***	−0.3706***
			(0.0173)	(0.0123)
Fixed Effects		i		i
R^2	0.0125	0.5225	0.0423	0.5239
N	189,724	189,724	189,724	189,724

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 4: Dif-Dif Results

Notes: Dependent variable is logged exports from East Asian ports to US ports at time t.

Table 4 reports the estimates of (2). Models 1+2 use destination coast as the interaction term, with Model 2 using Origin Fixed Effects. Likewise, Models 3+4 use Canal Usage as the interaction term, with Model 4 using Origin Fixed Effects. I re-express the interaction term estimates of each model in Table 5 to allow for easy interpretation.

Across all the modeling specifications of (2), there is evidence of the Panama Canal expansion improving East Coast traffic at the expense of other US ports and routes. Looking to Table 5, West Coast imports from East Asia fell by more than 21 percent after the Panama Canal's expansion (relative to the East Coast). Traffic through the Suez Canal fell by slightly margins at approximately 29 percent (relative to Panama Canal traffic).

	East	
Origin FE	N	Y
Gulf	-15.9	-27.1
West	-21.5	-24.1
	Panama	
Origin FE	N	Y
No Canal	-24.6	-27.8
Suez	-29.1	-31.0

Table 5: Dif-Dif Summary

Notes: For each of the interaction coefficients $\hat{\beta}_k$, I computed $100 \times (\exp(\hat{\beta}_k) - 1)$ to compute the percent change in capacity growth relative to either the East Coast or routes using the Panama Canal.

4.2 Robustness Checks

4.2.1 All North American Trades Dif-Dif Estimation

Table 6 presents the results of estimating:

$$\ln\left(X_{ijt}\right) = \beta_0 + \beta_1 Post_t + \beta_2 Pan_{ijt} + \beta_3 (Post_t \times Pan_{ijt}) + \varepsilon_{ijt} \tag{3}$$

Please overlook the (slight) abuse of notation: ij refer to the listed origin/destination port for a voyage at time t. So for a port sequence $A \to B \to C$, AC correspond to ij. Moreover, equation (3) is estimated using data across all voyages/ports in the BlueWater data North American import series (no longer limited to East Asia to US).

	Model 1
Pan_{ijt}	-0.4125^{***}
	(0.0148)
$Post_t$	0.0406^{***}
	(0.0092)
$Post_t \times Pan_{ijt}$	0.2180^{***}
	(0.0178)
Num. obs.	96,317
R^2 (full model)	0.6322
R^2 (proj model)	0.0099
Adj. R^2 (full model)	0.6307
Adj. R^2 (proj model)	0.0058

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 6: Full Regression (Origin/Dest FE)

The interaction term implies $\exp(0.2180) - 1 = 24.4$ percent increase in Panama Canal traffic after 2016 relative to pre-Expansion for all North American voyages. This result is consistent with the 18 percent toal increase in Panama Canal traffic across all US ports.

4.2.2 Time Savings due to improved Canal congestion?

For routes that use the Panama Canal, how does total transit time change before/after the 2016 expansion? Perhaps the improvements to the Canal not only allowed for larger ships but also enabled all ships to navigate the Canal faster (e.g. reduced congestion).

The data show little evidence of this potential change. Table 7 provides the results of a simple factor model wherein I regress $Post_t$ on the (log of) voyage time while controlling for distance. The first and second columns of Table 7 use voyage data on non-Panama Canal trips. Likewise, the third and fourth columns use Panama Canal trips; the second and fourth columns include the interaction term between $Post_t \times \ln(Seamiles)$.

Looking to (Pan), total transit time post Canal Expansion increases by $\exp\{0.051\} \approx 1.052$, or 5 percent while controlling for distance. The interaction model (Pan 2) tells a similar story. Setting $Post_t = 1$, we have the following model:

$$\begin{aligned}\ln(Time) =& \upsilon_0 + \upsilon_1(Post_t = 1) + \upsilon_2 \ln(Seamiles) + \upsilon_3\Big((Post_t = 1) \times \ln(Seamiles)\Big) \\ =& \upsilon_0 + \upsilon_1 + (\upsilon_2 + \upsilon_3)\ln(Seamiles)\end{aligned}$$

Voyages in a Post Panama Canal Expansion world should experience an increase travel time if voyage is great than

$$Seamiles > \exp\left\{\frac{-(\gamma_0+\gamma_1)}{\gamma_2+\gamma_3}\right\} = \exp\left\{\frac{-(-8.713-5.211)}{1.273+0.557}\right\} = 2015.74 \text{ miles}$$

Since all voyages from East Asian ports are in excess of 2015.74 miles, the interaction model also suggests that travel time for trips using the Canal (East-Asia and the East Coast in particular) more likely than not increased.

Table 7: Canal-Route Time Differences

	Dependent variable:			
	log(Time)			
	(No-Pan 1)	(No-Pan 2)	(Pan)	(Pan 2)
$Post_t$	0.018^{***}	-0.183^{***}	0.051^{***}	-5.221^{***}
	(0.001)	(0.019)	(0.001)	(0.089)
$\ln(Seamiles)$	0.964^{***}	0.953^{***}	1.448^{***}	1.273^{***}
	(0.001)	(0.002)	(0.004)	(0.005)
$Post_t \times \ln(Seamiles)$		0.022^{***}		0.557^{***}
		(0.002)		(0.009)
Constant	-5.782***	-5.676^{***}	-10.369^{***}	-8.713^{***}
	(0.010)	(0.014)	(0.042)	(0.050)
Observations	111,405	111,405	78,319	78,319
R^2	0.881	0.881	0.576	0.594
Note:	*p<0.1; **p<0.05; ***p<0.01			

4.2.3 Whence Cost Saving?

Time savings are not the source of efficiency (trade costs) improvement. Rather, cost savings are more likely to appear in using more cost-efficient maritime shipping (on a TEU/mile-basis) relative to faster/more expensive overland shipping modes. Figure 16 illustrates increased travel time to route East Asian imports to NYC through the Panama Canal relative to Los Angeles per FAF4 region. Additional shipping time to contested markets, such as MidWestern cities, ranges from 11-12.5 days.

5 Changes to transportation cost: Internal Trade

Quantifying the full impact of the Panama Canal Expansion must be done in view of product-specific shipping cost heterogeneity. As indicated by Figure 16, shipping through the Panama Canal entails a longer total shipping time from East Asian ports to US markets. To the extent that product shipments are more sensitive to new costs incurred through increased shipping time (typically though increased inventory costs) relative to cost savings per unit transit cost, the expansion of the Panama Canal is of little consequence. Thus, the Canal's expansion reduction in transportation costs will depend on the interaction of product-route characteristics for a given shipment location.

Figure 10 provides a backdrop for how the cost saving exercise is performed. A shipper from East Asia chooses to ship commodity k to destination i per mode m in year t. The crucial choice here is to which coast to import to: West or East. A shipper chooses to import through a port p that minimizes total shipping costs, namely transit cost summed with inventory cost, as in equation (5). I use the following list of ports for this cost saving exercise.

Port	**Coast**	**2015 Share of US Import Capacity (BlueWater)**
Los Angeles/South Beach	West	15.3
Oakland/San Francisco	West	11.6
Seattle/Tacoma	West	8.3
New York/New Jersey	East	14.2
Savannah	East	12.0
Norfolk	East	9.1
Charleston	East	4.8
Baltimore	East	0.7

Table 8: Select Ports

I selected these ports on because they: (i) made up a significant share of US imports (by 2015 TEU capacity). In total, these 8 ports account for approximately 76 percent of US imports of goods from East Asia; and, (ii) each one of these ports was either able to handle Post-Panamax traffic prior to 2016 and/or made investments to be ready post expansion.

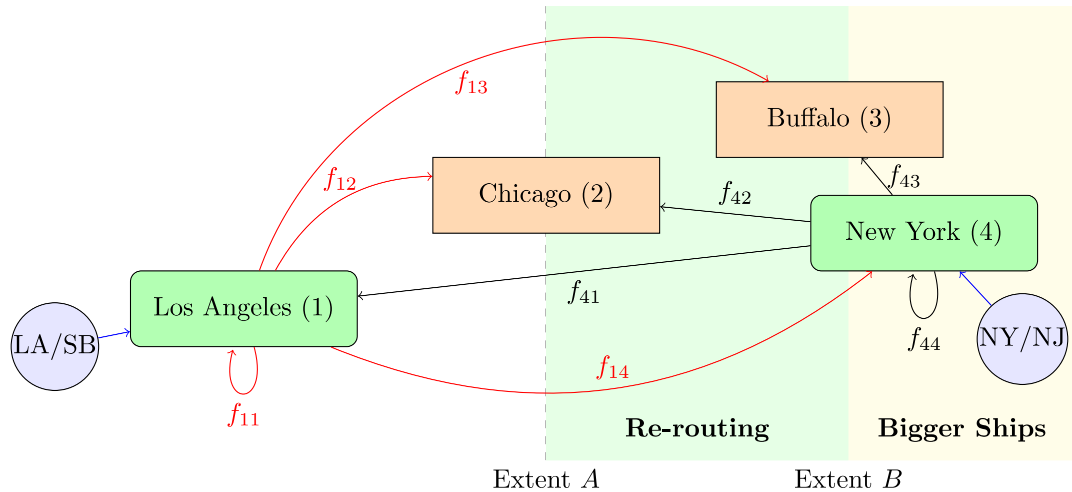


Figure 10: Shipping Decision Map

Notes: The figure above is commodity k and mode m specific. The cost minimizing BlueWater port for the West (East) Coast is LA/SB (NY/NJ). BlueWater ports are mapped to their closest FAF4 regions shaded in green (e.g. FAF4 regions with ports). Chicago and Buffalo are included as examples of internal shipping regions without ports. f_{ij} represents the decision to ship goods from FAF4-port region i to region j. Red (black) edges represent the flow of goods from the West (East) Coast.

Variable/Parameter	**Description**	**Value**	**Source**
μ^m	cost per teu/mile	train: \$0.784	CBO
		truck: \$2.44	CBO
ψ^m	average speed	train: 38 mph	Punwani (2013)
		truck: 47 mph	Punwani (2013)
θ_{pt}	cost per teu/mile	See Table 11	UNCTAD
$miles^m_{ip}$	miles between i and p		Author's calculation
$seamiles_p$	nautical miles between EA and p		BlueWater/author's calculation
$seatime_p$	min travel between EA and p		BlueWater/author's calculation
α^m_{ik}	share of mode m's import k's value to i		FAF4
α_{ik}	share of import k's value to i		FAF4
α_i	share of import i's value to relative to US		FAF4
γ_k	\$ per ton of k		FAF4
c_k	tons per container of k	14	Kirk (2010)
r_d	daily interest rate	$10\%/365 = 2.7 \times 10^{-4}$	Assumed

Table 9: Cost parameters

Notes: "EA" stands for East Asia. Further details of cost parameters are found in the Appendix.

How I Compute Cost Savings

I. Fix location i, commodity k, and internal mode of transportation m. For each port p:

II. Compute the (maritime) transit cost of shipping to port p from East Asia:

- Use \$0.219 per TEU-mile as the base rate for Los Angeles in 2015.
- Adjust the base rate by port efficiency-estimate changes to calculate the freight rates for all other ports both before and after the expansion.
- Record the total time at sea from BlueWater (this will go into inventory costs later).

III. Compute the inland transit cost of shipping.

- Use \$0.784 TEU/mile for rail and \$2.44 TEU/mile for rail
- Use an average speed of 38 mph for rail and 47mph for truck.

IV. Compute total cost of shipping from East Asia:

- Sum together maritime and inland shipping costs to get total transportation costs.
- Total inventory costs are determined by the total number of days in transit (days at sea plus days using mode m) and the value/container of commodity k.

V. Determine the cost minimizing port p (and associated cost) from: (i) East Coast Port pre-Expansion; (ii) East Coast Post-Expansion; and (iii) West Coast.

VI. Evaluate cost savings ΔC_{ik}^{m} are according to cases **C1**-**C3** (defined here).

5.1 Cost Saving Setup

Define inventory costs per day for commodity k:

$$I_k = r_d c_k \gamma_k \tag{4}$$

Cost of sending commodity k from East Asia to location i using internal mode m at time t is:

$$C_{ikt}^{m} = \min_{p} \left[\mu^m miles_{ip}^{m} + \theta_{pt} seamiles_p + \left(\frac{miles_{ip}^{m}}{\psi^m} + seatime_p \right) I_k \right] , \forall i, k, m \tag{5}$$

C_{ikt}^{m} is computed per Coast and per time t. Time t serves as a dummy variable with, $t = 0$ ($t = 1$) standing in for before (after) the Canal Expansion. Values for θ_{pt} are drawn from Table 11.

Calculating cost savings implies a point of comparison. FAF4 regions i that are located within the Midwest are the most likely to switch import Coasts (e.g. choose NY/NJ over LA/SB) as a result of the Canal Expansion. Thus, Chicago would accrue cost savings for shipping k through the cost-minimizing East Coast port at time $t = 1$ by mode m relative to the cost-minimizing West Coast port. However, computing cost savings for a region i already importing k through the East Coast by mode m at time $t = 0$ should be done differently. Take Buffalo from Figure 10 as an example. For $t = 0$ and $t = 1$, most commodities from East Asia will be shipped through NY/NJ.[12] Cost savings enjoyed by Buffalo will be the *sole* result of *using larger ships* arriving in the port NY-NJ, as opposed to *re-routing* as in the case of Chicago (due to larger ships). Calculating cost savings for Buffalo using LA/SB as the port of entry will overstate the benefits of the Canal Expansion. Using Figure 10, cost savings should be computed on the basis of whether a location i falls in the "Bigger Ships" region or the "Re-routing" region.

I define change in cost savings to region i for commodity k and mode m and the respective reference cost, namely ΔC_{ik}^{m} and $C_{ik}^{m,Ref}$, following this decision rule:

$$
\begin{aligned}
\boxed{\textbf{C1}} \text{ if } C_{ik}^{m,West} - C_{ik(t=0)}^{m,East} &> 0 \\
\Delta C_{ik}^{m} &= C_{ik(t=0)}^{m,East} - C_{ik(t=1)}^{m,East} \\
C_{ik}^{m,Ref} &= C_{ik(t=0)}^{m,East} \\
\boxed{\textbf{C2}} \text{ else if } C_{ik}^{m,West} - C_{ik(t=1)}^{m,East} &> 0 \\
\Delta C_{ik}^{m} &= C_{ik}^{m,West} - C_{ik(t=1)}^{m,East} \\
C_{ik}^{m,Ref} &= C_{ik}^{m,West} \\
\boxed{\textbf{C3}} \text{ else} \min\{C_{ik}^{m,West}, C_{ik(t=0)}^{m,East}, C_{ik(t=1)}^{m,East}\} &= C_{ik}^{m,West} \\
\Delta C_{ik}^{m} &= 0 \\
C_{ik}^{m,Ref} &= C_{ik}^{m,West}
\end{aligned}
$$

So $\Delta C_{ik}^{m} > 0$ means that product k should be shipped from some port on the East Coast, and that the degree of cost savings depends on whether i falls into the "Bigger Ships" or the "Re-routing" category as shown in Figure 10. In words, Case $\boxed{\textbf{C1}}$ includes cost savings to regions who continue to source goods from an East Coast port and the East Coast port is more efficient, Case $\boxed{\textbf{C2}}$ includes cost savings to regions who switch importing coasts, and Case $\boxed{\textbf{C3}}$ includes unaffected regions. Case $\boxed{\textbf{C1}}$ encompasses two sub-cases. Case $\boxed{\textbf{C1a}}$ is when the cost minimizing port on the East Coast stays the same before/after the Canal Expansion. Case $\boxed{\textbf{C1b}}$ is when the cost minimizing port within the East Coast changes (e.g. it becomes cheaper to ship machinery to Cleveland through the port of NY/NJ after the Expansion compared to the previous cost-minimizing route through

[12] Some commodities, particularly high-value commodities, are shipped to FAF4 regions near East Coast ports through West Coast ports. This is the message of Figure 2.

the port of Baltimore). ΔC_{ik}^{m} and $C_{ik}^{m,Ref}$ for both sub-cases are the same. I incorporate these sub-cases allows to better decompose all trade diversions: trade diversion between coasts and within coast.

Given all the cost saving cases, define total cost savings for region i for product k as:

$$S_{ik} = \sum_{m} \mathbb{1}\{\Delta C_{ik}^{m} > 0\}\alpha_{ik}^{m}\Delta C_{ik}^{m} \tag{6}$$

Likewise, the percentage savings enjoyed by i for good k being imported through cost-minimizing port is:

$$\hat{S}_{ik} = \frac{\sum_{m} \mathbb{1}\{\Delta C_{ik}^{m} > 0\}\alpha_{ik}^{m}\Delta C_{ik}^{m}}{\sum_{m} \alpha_{ik}^{m} C_{ik}^{m,Ref}} \tag{7}$$

Once $\hat{S}_{ik}$ is computed,adjust this amount by the total quantity of *current* imports X_{ik} to arrive at the total (respectively percentage) savings for region i:

$$S_i = \sum_{k} X_{ik}\hat{S}_{ik} \quad \text{and} \quad \hat{S}_i = \frac{\sum_{k} X_{ik} \sum_{m} \mathbb{1}\{\Delta C_{ik}^{m} > 0\}\alpha_{ik}^{m}\Delta C_{ik}^{m}}{\sum_{k} X_{ik} \sum_{m} \alpha_{ik}^{m} C_{ik}^{m,Ref}} \tag{8}$$

Aggregating over regions i yields the total (respectively percentage) savings

$$T_i = \sum_{i} S_i \quad \text{and} \quad \hat{T}_i = \frac{\sum_{i}\sum_{k} X_{ik} \sum_{m} \mathbb{1}\{\Delta C_{ik}^{m} > 0\}\alpha_{ik}^{m}\Delta C_{ik}^{m}}{\sum_{i}\sum_{k} X_{ik} \sum_{m} \alpha_{ik}^{m} C_{ik}^{m,Ref}} \tag{9}$$

The following subsections describe how I estimate changes in maritime transportation costs (θ_{pt}) and inventory costs.

5.1.1 Port Efficiency and Cost Saving

I use Blonigen and Wilson (2008)'s approach to estimate port efficiencies, which in turn, are then used to adjust shipping costs to port p before/after the Panama Canal expansion. For East Coast ports, I interpret efficiency gains to be the result of investing in port infrastructure. These investments, in turn, would allow for large Post-Panamax container ships to unload at East Coast ports.

Blonigen and Wilson use a quasi-gravity model structural estimation strategy to compute port efficiencies. Efficiency is derived from a particular port's contribution to import charges. The US Census Bureau defines import charges as

> . . . the aggregate cost of all freight, insurance, and other charges (excluding U.S. import duties) incurred in bringing the merchandise from alongside the carrier at the port of exportation in the country of exportation and placing it alongside the carrier at the first port of entry in the United States.

Blonigen and Wilson justify their use of import charges via a "definition decomposition." Based of the preceding quote, import charges are comprised of the following components:

1. costs associated with loading the freight and disembarking from the foreign port;
2. costs connected with transportation between ports; and,
3. costs associated with US port arrival and unloading of the freight.

The second component is easily identified in the data (e.g. freight costs, insurance, distance, etc). The second component is accounted for using distance and value per weight as respective proxies for freight costs and insurance; Blonigen and Wilson are able to justify this modeling choice via Clark, Dollar and Micco (2004), who show that both variables are strongly correlated with what each proxies. The first and third can be identified via fixed effects estimates: the contribution of a particular port to import charges.

I use Peter Schott's Harmonized System, ten digit (e.g. HS10) level imports and exports for containerized shipments.[13] I aggregate the data to the HS6 level to ease the computational burden of product fixed-effects and to maintain consistency with Blonigen and Wilson (2008). The import (export) data identify the *U.S. custom district* of entry (origin) and the *foreign country* of origin (entry). U.S. custom districts are coarser regions which include (potentially) many ports. However, for each of the ports used in this study, the name of the port corresponds with the largest port within the given Custom District.[14] As for foreign countries j, I develop a longitude/latitude coordinate proxy. I devise this location proxy via coordinate data supplied by AtoBviaC Ltd, a UK maritime logistics consulting group. I use AtoBviaC's free list of longitude/latitude coordinates across more than 3,450 ports throughout 180 different countries. For each country j, I simply averaged the longitude/latitude coordinates of each port within j to arrive at a representative location for j. I use the coordinates of US ports p for Custom District i.

I estimate port efficiencies by:

$$\begin{aligned}\frac{IC_{ijkt}}{Wgt_{ijkt}} =& \beta_0 + \beta_1 Dist_{ij} + \beta_2 Valwght_{ijkt} + \beta_3 IM\_Imbal_{ijkt} + \beta_4 EX\_Imbal_{ijkt} + \beta_5 Year_t \\ &+ \eta_i + \zeta_j + Pan_{ij} + Suez_{ij} + \xi_k + \beta_{51}(\eta_i \times Year_t) + \varepsilon_{ijkt} \end{aligned} \tag{10}$$

where: the left hand-side variable is the logged ratio of import charges IC_{ijkt} to containerized weight Wgt_{ijkt}; $Dist_{ij}$ is the logged nautical distance between i and j; $Valwght_{ijkt}$ is the logged

[13] See `https://sompks4.github.io/sub_data.html`. Data are purchased from the U.S. Census Bureau.

[14] U.S. Import and Export Merchandise trade statistics maintains within custom district, port-specific import data from 2001-present. Using customs import value data for all ports within a custom district, I identify which port of entry was a good representation of the custom district as a whole (i.e. which port had the largest share of custom import values). The majority of the custom districts' representative port of entry shared a common name (e.g the principle city of the Los Angeles customs district was also Los Angeles). The three exceptions to this matching rule include: Lardero TX (Brownsville TX), Minneapolis MN (Duluth MN), and Tampa FL (Jacksonville FL).

ratio of containerized values/weight; is IMB_{ijt} is a factor variable which captures the effect of export and import trade imbalances between ij at time t relative to balanced trade;[15] η_i (ζ_j) is the custom district (foreign country) fixed-effect; $Pan_{ij}(Suez_{ij})$ is a dummy variable indicating if the shortest nautical distance between i and j uses the Panama (Suez) canal; $Year_t$ is a dummy variable taking on unity if observation occurs in 2017 (post-expansion) and 0 if the observation takes places in 2015; and, ζ_k is an HS6 product fixed effect. All told, I use 8 U.S. ports, 158 countries, 5,328 HS6 product codes, and two years (namely 2015 and 2017).

I also estimate (10) following a specification more similar to Blonigen and Wilson (2008) by using (logged) import charges as the left hand-side variable and treating Wgt_{ijkt} as a predictor. Table 21 in the Appendix reports the results of both estimations. Note that Table 10 is provided to facilitate interpretation of coefficient estimates.

Table 10: Efficiency Differences

	Los Angeles	Not Los Angeles	**Difference**
$Year_t = 0$	β_0	$\beta_0 + \eta_i$	η_i
$Year_t = 1$	$\beta_0+\beta_5$	$\beta_0 + \eta_i + \beta_5 + \beta_{51}$	$\eta_i + \beta_{51}$
Difference	β_5	$\beta_5 + \beta_{51}$	β_{51}

Import Charge Improvement

Custom District (e.g. port) fixed effects η_i on import charges use Los Angeles as a reference. I set the 2015 Los Angeles shipping cost per TEU-mile at a base-rate of \$0.219. I obtain the shipping cost per TEU of the other (non Los Angeles ports) by multiplying the \$0.219 rate by $1 - e^{\eta_i}$. Likewise, the 2017 Los Angeles shipping cost per TEU-mile is derived by adjusting the base-rate by $1 - e^{\beta_5}$ and other ports by $1 - e^{\eta_i+\beta_5+\beta_{51}}$. I present the results below in Table 11.

[15] Let IM_{ijt} (EX_{ijt}) be the value of imports (exports) to i from j (to i from j) at time t. Since roughly 30\$ of all unilateral trades are zero, I introduce IMB_{ijt} as dummy-variable with the following levels:

$$IMB_{ijt} = \begin{cases} IM & \text{if } \dfrac{IM_{ijt}}{EX_{ijt}} > 1.2 \text{ or } IM_{ijt} > 0 \text{ and } EX_{ijt} = 0 \\ BAL & \text{if } 0.8 \leq \dfrac{IM_{ijt}}{EX_{ijt}} \leq 1.2 \text{ or } IM_{ijt} = EX_{ijt} = 0 \\ EX & \text{if } \dfrac{IM_{ijt}}{EX_{ijt}} < 0.8 \text{ or } IM_{ijt} = 0 \text{ and } EX_{ijt} > 0 \end{cases}$$

Port	Pre-Expansion		Post-Expansion		
	Percent Reduction	Cost	Percent Reduction	Cost	Change
Baltimore	14%	0.188 $ per TEU-mile	20%	0.176 $ per TEU-mile	6 percentage points
Charleston	4	0.210	14	0.189	10
Tacoma	8	0.201	13	0.190	5
Norfolk	6	0.206	12	0.192	6
Savannah	10	0.196	10	0.196	0
Oakland	6	0.206	6	0.206	0
NY/NJ	-3	0.225	4	0.211	7
Los Angeles	0	0.219	0	0.219	0

Table 11: Port Efficiency Results
Notes: Values in the Percent Reduction columns are relative to Los Angeles's 2015 efficiency as measured in terms of unit-import charges. These differences are used to adjust $ per TEU shipping costs using $0.219 as the base-rate. Coefficients that are not statistically different from zero (0) are set to zero (0) when estimating the percent reductions. For instance, since the estimate for β_5 is insignificant, Los Angeles's shipping cost $ per TEU does not change from 2015 to 2017. Finally, the Change column reports the difference between pre and post expansion efficiencies, namely $1 - e^{\beta_{51}}$.

5.1.2 Inventory Costs

I create a SCTG2 commodity to HS2 crosswalk based on the written description of each code (e.g. SCTG2 code 1 groups "Live animals/fish" and HS2 section heading 1 groups "Animals; live"). I then remove commodities that either correspond to HS2 bulk commodities[16] or STCG2 commodities related to energy products/petroleum.[17]

The 2015 USD per ton value of each STCG2 comes from the entire universe of 2015 FAF4 imports (all foreign import regions, all international-shipping transport modes). I use the fact that a loaded TEU container, on average, weights 14 tons as per Kirk (2010) and Laursen (2015). I use this conversion rate and an annual interest rate of 10% (divided by 365 to get a daily rate) to compute the daily inventory cost per STCG2 commodity.

[16]This includes HS: 10 (cereals); 17 (sugars and sugar confectionery); 25 (salt; sulphur, earths, stones; plastering materials, lime and cement); 26 (ores, slag and ash); 28 (inorganic chemicals; organic and inorganic compounds of precious metals; of rare earth metals, of radio-active elements, and of isotopes); 29 (organic chemicals); 31 (fertilizers); and 44 (wood and articles and articles of wood; wood charcoal).

[17]This includes SCTG2 codes 15-19 and HS2 codes 27 and 28.

STCG2	STCG2 Description	HS2	USD/Ton	USD/Container	Inventory Cost
42	Mixed freight	93	$ 25,027.52	$ 350,385.28	$ 96.00
38	Precision instruments	90	$ 18,920.39	$ 264,885.46	$ 72.57
37	Transport equip.	88	$ 16,644.49	$ 233,022.86	$ 63.84
40	Misc. mfg. prods.	91	$ 16,146.36	$ 226,049.04	$ 61.93
35	Electronics	85	$ 15,818.18	$ 221,454.52	$ 60.67
21	Pharmaceuticals	30	$ 13,440.10	$ 188,161.40	$ 51.55
34	Machinery	84	$ 7,985.62	$ 111,798.68	$ 30.63
36	Motorized vehicles	87	$ 6,714.02	$ 93,996.28	$ 25.75
30	Textiles/leather	63	$ 6,502.43	$ 91,034.02	$ 24.94
39	Furniture	94	$ 6,107.75	$ 85,508.50	$ 23.43
5	Meat/seafood	2	$ 5,300.72	$ 74,210.08	$ 20.33
9	Tobacco prods.	24	$ 4,934.91	$ 69,088.74	$ 18.93
23	Chemical prods.	32	$ 3,280.43	$ 45,926.02	$ 12.58
1	Live animals/fish	1	$ 2,898.98	$ 40,585.72	$ 11.12
24	Plastics/rubber	39	$ 2,734.57	$ 38,283.98	$ 10.49
7	Other foodstuffs	21	$ 2,614.37	$ 36,601.18	$ 10.03
8	Alcoholic beverages	22	$ 2,419.00	$ 33,866.00	$ 9.28
33	Articles-base metal	73	$ 2,271.80	$ 31,805.20	$ 8.71
6	Milled grain prods.	11	$ 2,095.55	$ 29,337.70	$ 8.04
29	Printed prods.	49	$ 1,964.27	$ 27,499.78	$7.53
28	Paper articles	48	$ 1,700.66	$ 23,809.24	$ 6.52
3	Other ag prods.	7	$ 1,278.09	$ 17,893.26	$ 4.90
41	Waste/scrap	81	$ 1,165.14	$ 16,311.96	$ 4.47
4	Animal feed	4	$ 885.80	$ 12,401.20	$ 3.40
27	Newsprint/paper	49	$ 818.12	$ 11,453.68	$ 3.14

Table 12: SCTG2 Imports Summary

5.1.3 Distance, time, and cost from East Asia to US Markets?

Both transportation costs and inventory costs are functions to US markets of functions of distance and travel time. In addition, per-unit, per-mode internal transportation costs are also needed for this stage of the exercise. In the following list, I describe the travel speed and distance per mode of transportation. For internal transport modes, I also list the per-unit cost.

- **Maritime**: I calculate the median time (days) between port p and all East Asian ports found in BlueWater data for 2015. Table 13 gives a side-by-side comparison of the median BlueWater transit time relative to a direct trip (using median BlueWater calculated distances) assuming an average speed of 20 knots. On average, Median BlueWater trips are 4.74 days and 25% longer relative to direct time.

- **Rail**: I set ψ^{train} to 38mph as per (Punwani, 2013, p.1).
- **Truck**: I assume that freight truckers will be operating in teams and following current hours-of-service (HOS) regulations. Average freight truck speed is $\psi^{truck} = 47$mph (Punwani, 2013, p.6).

Port	Median BlueWater Days	Author's Calculations	Median Rail Time (Distance)	Median Truck Time (Distance)
LA/South Beach	16 days	12.91 days	2.6 days (2,370 miles)	1.8 days (2,034 miles)
Oakland	19	13.61	3.11 (2,838)	2.00 (2,258)
Tacoma	15	11.37	3.22 (2,938)	2.02 (2276)
NY-NJ	30	25.9	1.52 (1,389)	0.86 (969)
Norfolk	32	26.45	1.23 (1,122)	0.71 (799)
Savannah	28	23.4	1.40 (1,279)	0.81 (908)
Baltimore	33	27.24	1.23 (1,123)	0.69 (780)
Charleston	29	23.19	1.50 (1,370)	0.76 (861)

Table 13: Time from East Asian ports

Notes: For my own calculations, I use my estimated distances and assume an average vessel speed of 20 knots. The median time and distance refer to the (unweighted) time and distance between a given port and FAF4 region.

5.2 Results

5.2.1 Region Specific

Table 14 summarizes the results of total savings by cost saving case. Given 2015 imports quantity levels, rerouting traffic through cost-minimizing ports should generate approximately 45.32 billion dollars in savings. The lion's share of these savings come from the "Bigger Ships" portion of Figure 10 (more than 90 percent). Cost savings from changing coasts amount to 2.82 billion USD or approximately 6 percent of all savings. Taken in sum, however, total savings as a percentage of total prior shipping costs (e.g. "Reference") boil down to slightly over 1 percent. Put a slightly different way, of all the regions that that experienced positive cost reductions, the weighted-average savings comes out to around 3.52 percentage points.

Case	Savings	Reference	Within Case Share	Total Savings Share
C1a	35.25 (bil USD)	1375.78 (bil USD)	2.56%	77.78%
C1b	7.25	429.69	1.69	16
C2	2.82	114.44	2.46	6.22
C3	0.00	2397.68	0	0
Total	45.32	4317.58	**1.05 (total)**	100

Table 14: Total Savings (in bil USD)

Looking now to Figure 11, most of the savings gains are concentrated along the Atlantic coast and decrease farther inland. Table 8, which provides the list and values of cost savings per FAF4 region, also bears this fact out. In percentage terms, FAF4 regions closer to the select East Coast ports save much more. Figure 11, in an indirect fashion, also points to the fact that even relatively small percentage savings can lead to large dollar savings if shipping volumes are sufficiently large. Demand for good k by region i will drive the absolute level of savings. In the absence of a more formal model, I estimate the relationship between product savings S_{ik} and: (i) logged 2015 per-capita income for region i (y_i); and (ii) logged average inland distance (across both rail and truck distances) between optimal port p^* and i (d_{ip^*}). I use a PPML estimator as per Silva and Tenreyro (2006) to address the presence of structural zeros in S_{ik}. Moreover, I also incorporate commodity fixed-effects FE_k to control for heterogeneity across commodity characteristics (e.g. inventory costs as a function of product value). The relationship between savings and logged per-capita income and logged distance is given by the following with robust standard errors given in parentheses.

$$S_{ik} = \underset{(3.84)}{-13.1} + \underset{(0.270)}{2.56}\, y_i - \underset{(0.058)}{0.291}\, d_{ip^*} + FE_k \tag{11}$$

Equation (11) suggests that increases in per-capita income are more significant indicator of predicted savings relative to distance. Indeed, this perhaps one of the reasons that a FAF4 region such as Cleveland Ohio can benefit from port improvements notwithstanding its distance from major East Coast ports (relative to faster trains/effectively shorter distance from West Coast ports).

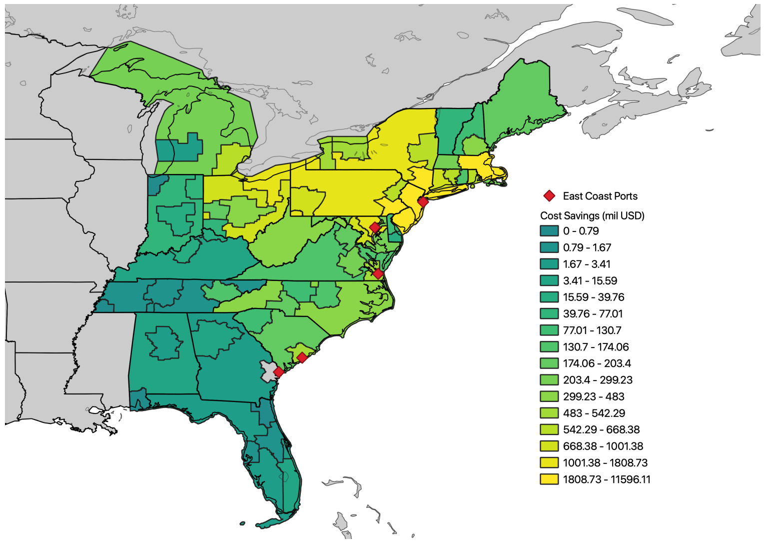


Figure 11: Cost Saving Map

5.2.2 Port Specific

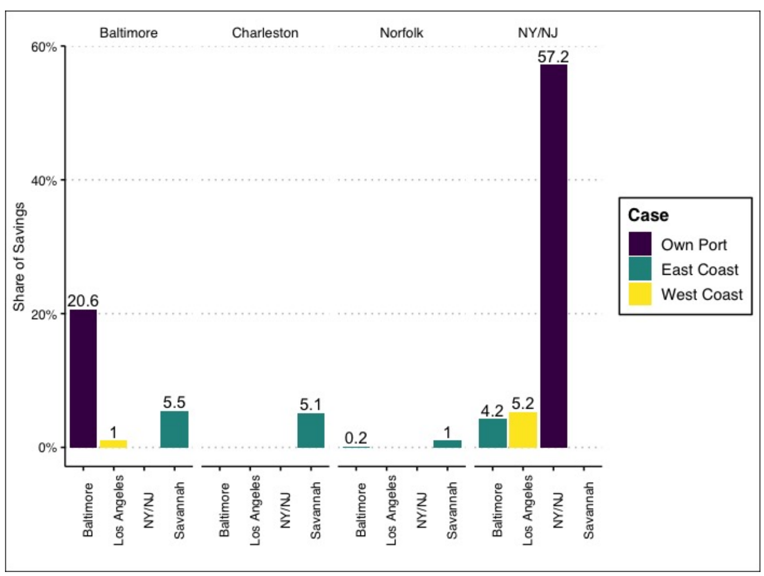


Figure 12: Port Distribution of Cost Savings

As Table 9 divides total savings across affected FAF4 regions, Figure 12 decomposes the same savings by optimal port. Top labels in Figure 12 are the four (4) positively impact ports. Port labels on the x-axis denote where the cost savings are coming from. “Own Port” refers to case **C1a** (cost savings generated from using the same East Cost port but now with better ships/better port infrastructure). The other two categories are savings from trade-diversions: “East Coast” (West Coast) captures re-shuffling among East Coast ports (across from West coast ports). The clear and unambiguous “winner” post-Panama Canal is New York/New Jersey with roughly 67 percent of total savings. Indeed, 4.2 percent (5.2 percent) of total savings go to New York/New Jersey from Baltimore (Los Angeles). Putting the total 9.2 percent figure (total gains to New York/New Jersey through trade diversion) in perspective, $9.2\% \times 45.32$(bil USD) ≈ 4.26 (bil USD) compared to the estimated 1.7 (bil USD) required to raise the Bayconne Bridge.

5.3 Discussion

The results of the preceding section do raise a number of concerns. In particular, the exact dollar amount of savings is sensitive to the following dimensions:

1. All cost savings are performed using 2015 data on imports from East Asia to i of k. Its reasonable to expect that differential trade cost reduction (see Table 22) would change import patterns in an general equilibrium framework.

2. Each region i *exclusively* uses the cost minimizing port * to import commodity k.

3. The relationship between changes and port efficiency and changes in total transportation costs have (potentially) disproportionate influence. I suspect that Baltimore does as well it does in the cost saving exercise (see Figure 12) because of how slight its effective maritime freight rates are. Taken in absolute terms, Baltimore is almost \$0.50 per TEU-mile cheaper than Los Angeles by 2017. Taking this sizeable cost difference and the fact that the cost-minimizing port commands all the traffic for region-commodity pair ik, Baltimore’s contribution to total cost savings are (artificially) large. Baltimore’s out-sized role in cost saving contributions is all the more bemusing given its small role in importing goods from East Asia in the first place (0.7 percent of all East Asian imports). In contrast, Savannah sees no improvement to maritime freight rates post Panama Canal Expansion (see Table 11). Consequently, approximately 12 percent of cost savings (roughly 5.4 bil USD) are generated by redirecting imports *away* from Savannah to other ports. Given Savannah’s significant role in importing goods from East Asia (12 percent of the US’s total), Savannah’s role in the cost-saving exercise is bizarre at best.

4. Total transportation costs are tightly linked to the conversion of weight to volume (e.g. tons to TEUs) and inland freight rates. For instance, the estimated total transportation cost of importing commodities from East Asia by boat and then by various inland transports to the continental US comes to the order of 4.317 *trillion* dollars.

All of these limitations highlight the fact that the cost saving estimates are likely overstated and would be improved a richer general equilibrium framework was used.

5.4 Robustness Check

Cost reductions depicted in Figure 11 are theoretical results. The best way to test the theoretical predictions of the cost saving model would be to: (i) estimate the trade elasticity with respect to transport costs; (ii) construct a counterfactual importing scheme given reduced transportation costs; and (iii) compare the predicted counterfactual trade flows against observed trade flows. This suggestion is among the most obvious and necessary extensions of the work here; future versions of this project will attempt to test the model's predictions in this way.

For the time being, I provide two points of *suggestive*, albeit limited, evidence that the qualitative predictions of the model are correct. First, I determine the number of TEU containers shipped to i of commodity k at time $t = \{2015, 2017\}$; denote this variable $CONT_{ikt}$. I obtain the number of TEUs shipped to region i from the cost minimizing port (read: FAF region containing cost minimizing port per FAF region-commodity pair) for each year $t = \{2015, 2017\}$ from FAF4 data.[18] I then convert shipped tons to containers via the 1 container: 14 tons ratio. I regress the predicted share of positive cost savings $\hat{S}_i > 0$ on the ratio of total containers shipped to i from cost minimizing port p at time 2017 relative to 2015, namely $r_i = CONT_{i(t=2017)}/CONT_{i(t=2015)}$. The results of this regression are reported in Table 15. Note that a 1 percentage point increase in predicted cost-savings is associated with 0.07 increase in the ratio of imports shipped to i in 2017 vs 2015 through the cost minimizing port.

[18] Note that $CONT_{ik(t=2015)}$ uses a different series than the one used to estimate the dollar cost savings implied by S_i and/or $\hat{S}_i$. Estimated dollar cost savings from $\hat{S}_i$ look at the *total* cost of shipping to ik (through *all* ports) prior to the Expansion and adjust by $\hat{S}_i$. In contrast, $CONT_{ikt}$ uses the observed flows from cost-minimizing port p subsequent to the Panama Canal expansion.

Table 15: State Ratio vs Predicted Cost Savings Share

	Dependent variable:
	r_i
$\hat{S}_i$	0.070***
	(0.022)
Constant	0.649***
	(0.061)
Observations	66
R^2	0.137
Adjusted R^2	0.123
Residual Std. Error	0.348 (df = 64)
F Statistic	10.126*** (df = 1; 64)
Note:	*p<0.1; **p<0.05; ***p<0.01

As a second check, I estimate:

$$\ln(CONT_{ikt}) = \gamma_0 + \gamma_1 FAF_i + \gamma_2 Year_t + \gamma_3 (FAF_i + Year_t) + \varepsilon_{ikt} \tag{12}$$

where FAF_i is FAF region i's relative to FAF4 region "New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part)."[19] I estimate (12) for all regions i such that $\hat{S}_i > 0$. The goal of estimating (12) is to use values of $\gamma_1 + \gamma_3$ in one final regression. In words, $\gamma_1 + \gamma_3$ describes the log point difference between New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part) and region i in 2017. The idea here is to see how predicted cost savings $\hat{S}_i$ correspond to $\gamma_1 + \gamma_3$; if the the two are positively correlated, then this would lend further credibility to the model's predictive accuracy. The final regression model is specified here:

$$\gamma_1 + \gamma_3 = \theta_0 + \theta_1 \hat{S}_i + \varepsilon_i \tag{13}$$

Table 16 reports the desired result: a 1 percentage point increase in predicted cost savings in i is

[19] This FAF4 region is used as the reference level since this the region with the smallest positive percentage growth, e.g. $r_i \approx 1$ for this region. Thus when interpreting $\gamma_1 + \gamma_3$, if $\gamma_1 + \gamma_3 > 0$ this means that import growth in region i is not only relatively increasingly (compared to New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part)), it is also absolutely increasing.

associated with a 0.616 log point increase in region i relative to growing region New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part).

Table 16: Log Point Increase vs Predicted Cost Savings Share

	Dependent variable:
	$\gamma_1 + \gamma_3$
$\hat{S}_i$	0.616***
	(0.109)
Constant	−5.845***
	(0.299)
Observations	65
R^2	0.335
Adjusted R^2	0.324
Residual Std. Error	1.701 (df = 63)
F Statistic	31.714*** (df = 1; 63)
Note:	*p<0.1; **p<0.05; ***p<0.01

Both the results of the ratio check and equation (13) indicate that, in directional terms at least, the cost saving exercise maintains some degree of explanatory credibility.

6 Conclusion

The 2016 Panama Canal expansion substantially impacted the market for East Asian imports to North American markets in general and to US markets in particular. Using a combination of maritime shipping records, transportation infrastructure data, and internal trade flows, my analysis suggests that: (i) total imports to US ports increased by 18 percent after the Canal's expansion relative to before; (ii) East Coast ports gained traffic at the expense of West Coast and Gulf Ports; (iii) cost savings, inclusive of import destination and import product characteristics, per positively affected regions average around 3.52 percentage points; and (iv) the vast majority of cost savings are attributable regions importing the same goods through the same East Coast ports but now using larger ships. Cost savings to US markets as a result of switching importing coasts while sizeable—3.2 bil USD (7.2 percent of 45.32 bil USD come from rerouting goods away from Los Angeles)—are relatively less significant compared to gains enjoyed from solely using better (and often) different East Cost ports. Changes in the observed patterns of East Asian markets are robust to larger containerized shipping trends. Likewise, the predictions of the cost saving exercise are directionally consistent with observed changes to imports before and after the Canal's expansion. Future extensions of this work will include incorporating cost saving estimates into a richer general equilibrium work to increase the accuracy and precision of changes in import flows.

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7 Appendix

7.1 Data Work

7.1.1 Blue Water Data

Origin	Destination	time	type	id	Origin_name	Origin_code
NewOrleansLA	HoustonTX	11	S	V7	New Orleans LA	USMSY
HoustonTX	JacksonvilleFL	5	M	V7	Houston TX	USHOU
CapeTown	Durban	8	M	V7	Cape Town	ZACPT
Durban	Maputo	2	M	V7	Durban	ZADUR
Maputo	RichardsBay	7	M	V7	Maputo	MZMPM
RichardsBay	Malongo	3	T	V7	Richards Bay	ZARCB

Origin_country_un_code	Origin_country_name	Destination_name	Destination_code	Destination_country_un_code	Destination_country_name	hops
US	United States	Houston TX	USHOU	US	United States	8
US	United States	Jacksonville FL	USJAX	US	United States	8
ZA	South Africa	Durban	ZADUR	ZA	South Africa	8
ZA	South Africa	Maputo	MZMPM	MZ	Mozambique	8
MZ	Mozambique	Richards Bay	ZARCB	ZA	South Africa	8
ZA	South Africa	Malongo	AOMAL	AO	Angola	8

WeeklyCapacity	month	year	pan	Origin_Coast	Destination_Coast	lon_o
598	Aug	2014	0	Gulf	Gulf	-89.93096
598	Aug	2014	0	Gulf	East	-95.21
598	Aug	2014	0	Non-US	Non-US	18.25
598	Aug	2014	0	Non-US	Non-US	31.01
598	Aug	2014	0	Non-US	Non-US	32.58322
598	Aug	2014	0	Non-US	Non-US	32.03768

lat_o	lon_d	lat_d	lon_change	lat_change	suez	year_dummy
30.06881	-95.21	29.45	West	South	0	0
29.45	-81.65565	30.33218	East	North	0	0
-33.55	31.01	-29.51	East	North	0	0
-29.51	32.58322	-25.96553	East	North	0	0
-25.96553	32.03768	-28.78301	West	South	0	0
-28.78301	15.03333	-6.61667	West	North	0	0

Table 17: Blue Water Data

Source: Blue Water Reporting and author's calculations.

Notes: Port and country codes correspond to UN/LOCODE (2011) location codes. **hops** refers to the edge-length of the computed shortest path (based on schedule days) between the listed origin and destination ports. For instance, Table 17 features a voyage from New Orleans, United States to Malongo, Angola. This voyage has a total of 6 hops compared to a theoretical 8 hops.

7.1.2 Ocean Current Data

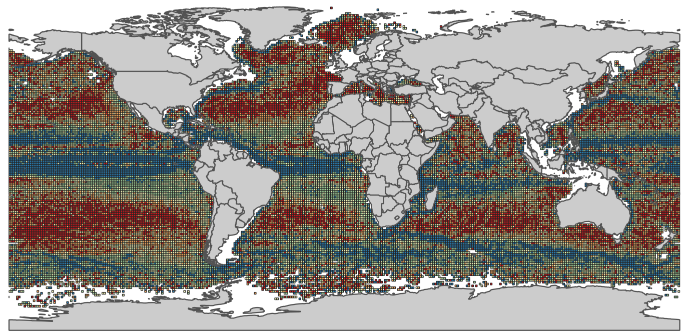

Figure 13: Ocean Current Surface Speed Map
Source: Data provided by Asia-Pacific Data Research Center, which is a part of the International Pacific Research Center at the University of Hawaii at Mānoa, funded in part by the National Oceanic and Atmospheric Administration (NOAA).

Velocity measurement data come from Argo floats (see `http://www.argo.ucsd.edu/How_Argo_floats.html`) and are averaged into $1^{\circ} \times 1^{\circ}$ bins by Asia-Pacific Data Research Center. Figure 13 depicts average surface velocity *speed* (the scalar dimension of velocity) measured in knots. Average surface velocity map coverage is extensive: average surface velocity is available for more than 87 percent of global ocean surface area. The reporting coverage improves looking at year round ice-free oceans:[20] coverage is approximately 94 percent.

Table 18 reports surface ocean speed distribution. The mean and standard deviation speed are 0.298 knots and 0.248 knots respectively. Given the:

1. relatively small magnitude of current speed throughout the world's oceans;

2. computational burden and complexity of properly incorporating current velocity into path problems (e.g. a due south current with a speed of 2 knots will affect boats heading due north, due east, or due south differently); and,

3. fact that vessel speed is endogenous, as per the demand for shipping services

[20]The extent of Arctic and Antarctic ice is 60° N and 52° S, respectively. See `https://nsidc.org/data/nsidc-0265`.

I ignore current speeds in my shortest path calculations for maritime shipping.

Percentile	**Speed (knots)**
0%	0
10%	0.0756103
20%	0.1150815
30%	0.1498274
40%	0.1868721
50%	0.2290192
60%	0.2757383
70%	0.3324883
80%	0.4167496
90%	0.5583529
100%	6.0837649

Table 18: Ocean Current Speed Distribution

7.1.3 FAF4 Data

SCTG Group Code	**SCTG 2-digit covered**	**Description**
1G	01-05	Agriculture products and fish
2G	06-09	Grains, alcohol, and tobacco products
3G	10-14	Stones, non-metallic minerals, and metallic ores
4G	15-19	Coal and petroleum products
5G	20-24	Pharmaceutical and chemical products
6G	25-30	Logs, wood products, and textile and leather
7G	31-34	Base metal and machinery
8G	35-38	Electronic, motorized vehicles, and precision instruments
9G	39-43, 99	Furniture, mixed freight, misc. manufactured products, and commodity unknown

Table 19: SCTG Description
Source: (Hwang et al., 2016, p. 61)

Table 20: FAF4 Regions

FAF4 Name	**ID**	**Region**
Alaska	20	West
Albany	361	NorthEast
Arkansas	50	South

Continued on next page

Table 20 – *Continued from previous page*

FAF4 Name	ID	Region
Atlanta	131	South
Austin	481	South
Baltimore	241	South
Baton Rouge	221	South
Beaumont	482	South
Birmingham	11	South
Boston (MA)	251	NorthEast
Boston (NH)	331	NorthEast
Rhode Island	441	NorthEast
Buffalo	362	NorthEast
Charleston	451	South
Charlotte	371	South
Chicago (IL)	171	MidWest
Chicago (IN)	181	MidWest
Cincinnati (KY)	211	MidWest
Cincinnati (OH)	391	MidWest
Cleveland	392	MidWest
Columbus	393	MidWest
Corpus Christi	483	South
Dallas	484	South
Dayton	394	MidWest
Denver	81	West
Detroit	261	MidWest
El Paso	485	South
Fort Wayne	183	MidWest
Fresno	65	West
Grand Rapids	262	MidWest
Greensboro	372	South
Greenville	452	South
Hartford	91	NorthEast
Houston	486	South
Idaho	160	West
Indianapolis	182	MidWest
Iowa	190	MidWest

Continued on next page

Table 20 – *Continued from previous page*

FAF4 Name	ID	Region
Jacksonville	121	South
Kansas City (KS)	201	MidWest
Kansas City (MO)	291	MidWest
Knoxville	473	South
Lake Charles	222	South
Laredo	487	South
Las Vegas	321	West
Los Angeles	61	West
Louisville	212	South
Maine	230	NorthEast
Memphis	471	South
Miami	122	South
Milwaukee	551	MidWest
Minneapolis	271	MidWest
Mississippi	280	South
Mobile	12	South
Montana	300	West
Nashville	472	South
New Mexico	350	West
New Orleans	223	South
New York (CT)	92	NorthEast
New York (NJ)	341	NorthEast
New York (NY)	363	NorthEast
New York (PA)	423	NorthEast
North Dakota	380	MidWest
Oklahoma City	401	South
Omaha	311	MidWest
Orlando	123	South
Philadelphia (DE)	101	NorthEast
Philadelphia (NJ)	342	NorthEast
Philadelphia (PA)	421	NorthEast
Phoenix	41	West
Pittsburgh	422	NorthEast
Portland (OR)	411	West

Continued on next page

Table 20 – *Continued from previous page*

FAF4 Name	**ID**	**Region**
Portland (WA)	532	West
Raleigh	373	South
Rest of AL	19	South
Rest of AZ	49	West
Rest of CA	69	West
Rest of CO	89	West
Rest of CT	99	NorthEast
Rest of DE	109	South
Rest of FL	129	South
Rest of GA	139	South
Rest of HI	159	West
Rest of IL	179	MidWest
Rest of IN	189	MidWest
Rest of KS	209	MidWest
Rest of KY	219	South
Rest of LA	229	NorthEast
Rest of MD	249	South
Rest of MA	259	NorthEast
Rest of MI	269	MidWest
Rest of MN	279	MidWest
Rest of MO	299	MidWest
Rest of NE	319	MidWest
Rest of NV	329	West
Rest of NH	339	NorthEast
Rest of NY	369	NorthEast
Rest of NC	379	South
Rest of OH	399	MidWest
Rest of OK	409	South
Rest of OR	419	West
Rest of PA	429	NorthEast
Rest of SC	459	South
Rest of TN	479	South
Rest of TX	489	South
Rest of UT	499	West

Continued on next page

Table 20 – *Continued from previous page*

FAF4 Name	**ID**	**Region**
Rest of VA	519	West
Rest of WA	539	West
Rest of WI	559	MidWest
Richmond	511	South
Rochester	364	NorthEast
Sacramento	62	West
Salt Lake City	491	West
San Antonio	488	South
San Diego	63	West
San Francisco	64	West
Savannah	132	South
Seattle	531	West
South Dakota	460	West
St. Louis (IL)	172	MidWest
St. Louis (MO)	292	MidWest
Tampa	124	South
Tucson	42	West
Tulsa	402	South
Honolulu	151	West
Vermont	500	NorthEast
Norfolk	512	South
Washington (DC)	111	South
Washington (MD)	242	South
Washington (VA)	513	West
West Virginia	540	South
Wichita	202	MidWest
Wyoming	560	West

7.1.4 Merged Maps

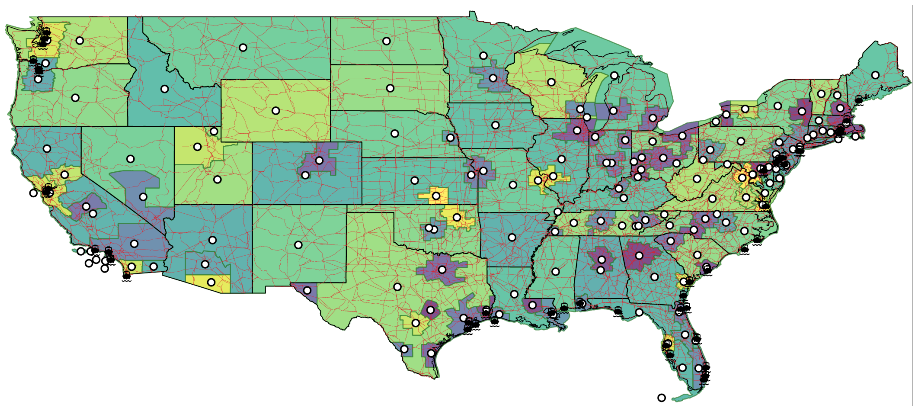

Figure 14: FAF4 Road Map

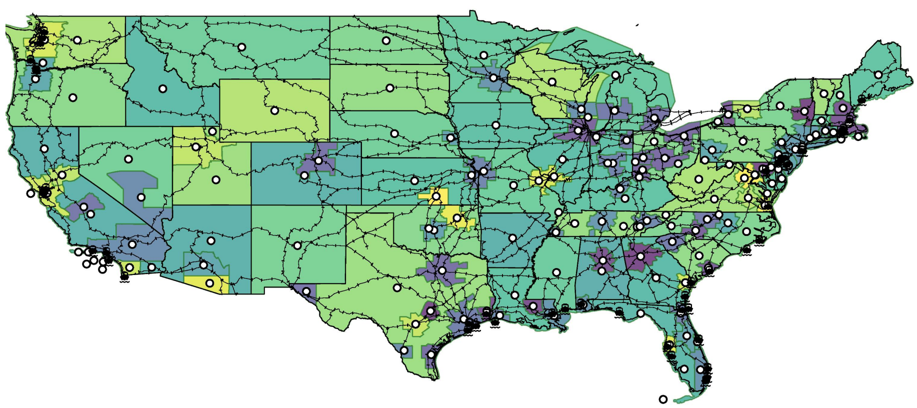

Figure 15: FAF4 Rail Map

Notes: FAF4 regions are colored on the basis on region name.

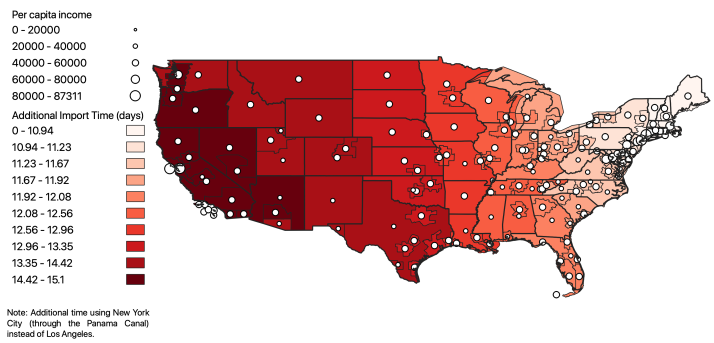

Figure 16: Extra Time Using the Panama Canal

	Dependent variable:		
	IC_{ijkt}/Wgt_{ijkt}		IC_{ijkt}
	(1)	(2)	(3)
$Dist_{ij}$	0.1446***	0.1406***	0.1136***
	(0.0246)	(0.0246)	(0.0242)
$Valwght_{ijkt}$	0.0004***	0.0004***	0.0003***
	(0.0000)	(0.0000)	(0.0000)
imbEX	0.0547***	0.0143	0.0367***
	(0.0088)	(0.0109)	(0.0086)
imbIM	0.5686***	0.6654***	0.5406***
	(0.1611)	(0.1698)	(0.1580)
Baltimore	−0.1294***	−0.1285***	−0.2129***
	(0.0161)	(0.0161)	(0.0158)
Charleston	−0.0373***	−0.0364***	−0.0652***
	(0.0137)	(0.0137)	(0.0134)
New York	0.0265**	0.0290**	0.0252**
	(0.0115)	(0.0115)	(0.0113)
Norfolk	−0.0566***	−0.0503***	−0.0911***
	(0.0148)	(0.0148)	(0.0145)
San Francisco	−0.0450***	−0.0366**	−0.1330***
	(0.0142)	(0.0142)	(0.0139)
Savannah	−0.1158***	−0.1109***	−0.1259***
	(0.0131)	(0.0132)	(0.0129)
Seattle	−0.0722***	−0.0630***	−0.1551***
	(0.0152)	(0.0153)	(0.0149)
$Year_t$	−0.0106	−0.0203*	−0.0104
	(0.0113)	(0.0115)	(0.0111)
Pan_{ij}	−0.0019	0.0001	−0.0315*
	(0.0170)	(0.0170)	(0.0166)
$Suez_{ij}$	0.0927***	0.0947***	0.0872***
	(0.0145)	(0.0145)	(0.0142)
Baltimore $\times Year_t$	−0.0521**	−0.0502**	−0.0547**
	(0.0217)	(0.0217)	(0.0213)
Charleston $\times Year_t$	−0.1042***	−0.1085***	−0.1003***
	(0.0184)	(0.0184)	(0.0180)
New York $\times Year_t$	−0.0615***	−0.0668***	−0.0656***
	(0.0148)	(0.0148)	(0.0145)
Norfolk $\times Year_t$	−0.0679***	−0.0804***	−0.0780***
	(0.0197)	(0.0198)	(0.0193)
San Francisco $\times Year_t$	−0.0290	−0.0439**	−0.0268
	(0.0195)	(0.0197)	(0.0192)
Savannah $\times Year_t$	−0.0202	−0.0256	−0.0190
	(0.0177)	(0.0177)	(0.0173)
Seattle $\times Year_t$	−0.0513**	−0.0642***	−0.0462**
	(0.0209)	(0.0210)	(0.0205)
imbEX:year2017		0.0744***	
		(0.0120)	
imbIM:year2017		−0.1616*	
		(0.0911)	
Wgt_{ijkt}			0.8836***
			(0.0010)
Num. obs.	349,102	349,102	349,102
R^2	0.2045	0.2046	0.7729

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 21: Efficiency Coefficients

7.1.5 More on parameter estimates

What is the per teu per mile per transport mode? Answering this question either requires a pretty involved calibration exercise and/or finding historic freight rates across a large number of shipping markets. Either approach is fairly data-intensive. As of 04/28/2020, here's what I have:

1. **Maritime**

   - **Sea Point Group**: $\boxed{\$0.8 \text{ per TEU-mile}}$ Using December 2017 freight rates, Sea Point Group estimates that the 6,000 mile journey between Shanghai/Hong Kong to Long Beach (CA) is $4,800 per TEU. A few limitations here include shipping costs a year after Panama and not knowing ship size.
   - **UNCTAD**: $\boxed{\$0.219 \text{ per TEU-mile}}$ UNCTAD's *2018 Review of Maritime Transport*[21] gives 2016 freight costs per FEU (forty-foot container equivalent unit) for Shanghai to the West Coast and to the East Coast. I multiply this cost by 0.7 since the cost of a FEU container is ≈ 30% more than a TEU.[22] Using BlueWater 2015 median distances between Shanghai-West Coast and Shanghai-East Coast ports (from **Port List**), I find a TEU-mile cost of ≈ $0.11 (≈ $0.33) for the West Coast (East Coast) ports. I take a simple average to get ≈ $0.219 per TEU-mile
   - **Zim Integrated Shipping Services**: $\boxed{\$0.135 \text{ per TEU-mile}}$ Chaim Shacham estimates that the roundtrip slot cost for Post-Panamax (8,000 TEU) vessel using the Panama Canal going from Hong Kong to NYC is $850 per TEU Leach (2016). Using a distance of 6,300 mile distance between Hong Kong and NYC implies a one-way cost per TEU-mile of $0.135. Doubling the mileage (to include round trip distance) implies TEU-mile cost of $0.067.
   - **Army Corps of Engineers**: $\boxed{\$0.024 - \$0.03 \text{ per TEU-mile}}$ These estimates come from a U.S. Army Corps of Engineer report on improving the Port of Charleston's harbor to receive Post-Panamax traffic Kirk (2010). Cost per TEU mile is calculated for three routes using Panamax and Post-Panamax ships and 2010 market data. The Army Corps of Engineer report cost per TEU-mile range comes from comparing Panamax and Post-Panamax ships. The ratio of Post-Panamax to Pre-Panamax cost per TEU/mile is 0.8. I take this to mean that prior to the East Coast ports being able to accommodate 8,000> TEU ships, costs per TEU/mile were 20% higher relative to after improvements were implemented/Post-Panamax traffic began.

2. **Rail**

[21] See page 46 of `https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf`.

[22] See `https://market-insights.upply.com/en/containerized-sea-freight-is-it-time-to-switch-from-teu-to-feu`.

- **JOC**: $\boxed{\text{\$1.40 mean spot rate}}$ in June 2016 Ashe (2019)
- **CBO**: $\boxed{\text{\$0.784 – \$0.952 per TEU-mile}}$
- **Sea Point Group**: $\boxed{\text{\$2.50 per TEU-mile}}$

3. **Truck**

- **JOC**: $\boxed{\text{\$1.86 mean spot rate}}$ in June 2016 Ashe (2019)
- **CBO** $\boxed{\text{\$2.44 – \$2.92 per TEU-mile}}$

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7.2 Cost Savings Results

Table 22: Regional Cost Saving Summary

FAF4	Total Save	Total Ref	Percent
Charleston-North Charleston-Summerville, SC CFS Area	$4.88E+08	$8.18E+09	5.966 %
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (DC Part)	1.79E+07	3.51E+08	5.118
New York-Newark, NY-NJ-CT-PA CFS Area (NY Part)	8.22E+09	1.67E+11	4.926
New York-Newark, NY-NJ-CT-PA CFS Area (CT Part)	8.99E+08	1.87E+10	4.812
Hartford-West Hartford-East Hartford, CT CFS Area	5.43E+08	1.15E+10	4.729
New York-Newark, NY-NJ-CT-PA CFS Area (PA Part)	5.60E+08	1.21E+10	4.615
Baltimore-Columbia-Towson, MD CFS Area	1.04E+09	2.26E+10	4.582
Remainder of Massachusetts	2.84E+08	6.28E+09	4.52
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (MA Part)	1.98E+09	4.42E+10	4.479
New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part)	1.16E+10	2.59E+11	4.471
Remainder of Maine	1.89E+08	4.25E+09	4.449
Remainder of Connecticut	1.70E+08	3.82E+09	4.445
Remainder of Vermont	5.15E+07	1.20E+09	4.286
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (MD Part)	8.49E+08	1.98E+10	4.284
Albany-Schenectady, NY CFS Area	6.23E+08	1.46E+10	4.258
Remainder of New Hampshire	9.44E+07	2.28E+09	4.144
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (NH Part)	3.42E+08	8.27E+09	4.138
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (RI Part)	5.67E+08	1.39E+10	4.094
Remainder of New York	1.23E+09	3.25E+10	3.79
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (NJ Part)	2.49E+09	6.77E+10	3.683
Remainder of Maryland	2.47E+08	7.07E+09	3.489
Buffalo-Cheektowaga, NY CFS Area	5.15E+08	1.49E+10	3.455
Rochester-Batavia-Seneca Falls, NY CFS Area	4.98E+08	1.47E+10	3.393
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (DE Part)	1.00E+08	3.06E+09	3.268
Cleveland-Akron-Canton, OH CFS Area	1.76E+09	5.40E+10	3.259
Remainder of Delaware	2.95E+07	9.15E+08	3.228
Pittsburgh-New Castle-Weirton, PA-OH-WV CFS Area (PA Part)	9.72E+08	3.07E+10	3.169
Remainder of West Virginia	4.73E+08	1.51E+10	3.124

Table 22: Regional Cost Saving Summary

FAF4	Total Save	Total Ref	Percent
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (PA Part)	1.81E+09	5.81E+10	3.121
Remainder of Pennsylvania	1.79E+09	6.21E+10	2.888
Virginia Beach-Norfolk, VA-NC CFS Area (VA Part)	5.33E+08	2.00E+10	2.66
Remainder of Ohio	9.22E+08	4.50E+10	2.049
Richmond, VA CFS Area	2.30E+08	1.49E+10	1.544
Detroit-Warren-Ann Arbor, MI CFS Area	5.66E+08	4.35E+10	1.302
Dayton-Springfield-Sidney, OH CFS Area	1.76E+08	1.65E+10	1.072
Columbus-Marion-Zanesville, OH CFS Area	3.77E+08	3.73E+10	1.01
Remainder of Michigan	2.31E+08	2.66E+10	0.869
Fort Wayne-Huntington-Auburn, IN CFS Area	6.00E+07	8.25E+09	0.728
Remainder of South Carolina	1.99E+08	3.01E+10	0.661
Greenville-Spartanburg-Anderson, SC CFS Area	1.04E+08	1.62E+10	0.644
Charlotte-Concord, NC-SC CFS Area (NC Part)	1.75E+08	2.84E+10	0.615
Greensboro-Winston-Salem-High Point, NC CFS Area	1.29E+08	2.14E+10	0.604
Raleigh-Durham-Chapel Hill, NC CFS Area	1.67E+08	2.77E+10	0.602
Remainder of North Carolina	3.22E+08	5.40E+10	0.596
Remainder of Virginia	1.49E+08	2.87E+10	0.52
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (VA Part)	1.75E+08	3.48E+10	0.504
Cincinnati-Wilmington-Maysville, OH-KY-IN CFS Area (KY Part)	3.31E+07	7.35E+09	0.45
Knoxville-Morristown-Sevierville, TN CFS Area	1.32E+08	3.60E+10	0.366
Cincinnati-Wilmington-Maysville, OH-KY-IN CFS Area (OH Part)	6.83E+07	2.53E+10	0.27
Indianapolis-Carmel-Muncie, IN CFS Area	3.93E+07	3.07E+10	0.128
Remainder of Indiana	4.62E+07	3.64E+10	0.127
Louisville/Jefferson County-Elizabethtown-Madison, KY-IN CFS Area (KY Part)	1.90E+07	1.91E+10	0.1
Grand Rapids-Wyoming-Muskegon, MI CFS Area	3.33E+06	1.15E+10	0.029
Remainder of Kentucky	3.68E+06	4.41E+10	0.008
Birmingham-Hoover-Talladega, AL CFS Area	1.68E+06	2.11E+10	0.008
Remainder of Alabama	3.72E+06	4.81E+10	0.008
Mobile-Daphne-Fairhope, AL CFS Area	7.87E+05	1.05E+10	0.007
Jacksonville-St. Marys-Palatka, FL-GA CFS Area (FL Part)	7.92E+05	1.08E+10	0.007
Remainder of Florida	3.12E+06	4.32E+10	0.007
Orlando-Deltona-Daytona Beach, FL CFS Area	1.63E+06	2.29E+10	0.007
Tampa-St. Petersburg-Clearwater, FL CFS Area	1.55E+06	2.20E+10	0.007

Table 22: Regional Cost Saving Summary

FAF4	**Total Save**	**Total Ref**	**Percent**
Miami-Fort Lauderdale-Port St. Lucie, FL CFS Area	3.48E+06	5.05E+10	0.007
Remainder of Georgia	3.21E+06	7.85E+10	0.004
Atlanta-Athens-Clarke County-Sandy Springs, GA CFS Area	6.16E+06	1.53E+11	0.004
Memphis, TN-MS-AR CFS Area (TN Part)	6.95E+05	3.35E+10	0.002
Nashville-Davidson-Murfreesboro, TN CFS Area	1.30E+06	6.34E+10	0.002
Remainder of Tennessee	1.67E+06	8.15E+10	0.002

Table 23: Region Cost Saving Summary Cases

FAF4	**Case**	**Savings (USD)**	**FAF4 Share**
Albany-Schenectady, NY CFS Area	C1a	5.83E+08	93.45%
Albany-Schenectady, NY CFS Area	C2	4.08E+07	6.55
Atlanta-Athens-Clarke County-Sandy Springs, GA CFS Area	C1a	0.00E+00	0
Atlanta-Athens-Clarke County-Sandy Springs, GA CFS Area	C1b	6.16E+06	100
Baltimore-Columbia-Towson, MD CFS Area	C1a	1.02E+09	98.56
Baltimore-Columbia-Towson, MD CFS Area	C1b	1.49E+07	1.44
Birmingham-Hoover-Talladega, AL CFS Area	C1a	0.00E+00	0
Birmingham-Hoover-Talladega, AL CFS Area	C1b	1.68E+06	100
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (MA Part)	C1a	1.59E+09	80.5
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (MA Part)	C2	3.86E+08	19.5
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (NH Part)	C1a	2.61E+08	76.41
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (NH Part)	C2	8.07E+07	23.59
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (RI Part)	C1a	3.96E+08	69.77
Boston-Worcester-Providence, MA-RI-NH-CT CFS Area (RI Part)	C2	1.71E+08	30.23
Buffalo-Cheektowaga, NY CFS Area	C1a	4.93E+08	95.71
Buffalo-Cheektowaga, NY CFS Area	C2	2.21E+07	4.29
Charleston-North Charleston-Summerville, SC CFS Area	C1b	4.88E+08	100
Charlotte-Concord, NC-SC CFS Area (NC Part)	C1a	0.00E+00	0
Charlotte-Concord, NC-SC CFS Area (NC Part)	C1b	1.75E+08	100
Chicago-Naperville, IL-IN-WI CFS Area (IN Part)	C1b	5.56E+04	100
Cincinnati-Wilmington-Maysville, OH-KY-IN CFS Area (KY Part)	C1b	3.31E+07	100
Cincinnati-Wilmington-Maysville, OH-KY-IN CFS Area (OH Part)	C1a	0.00E+00	0
Cincinnati-Wilmington-Maysville, OH-KY-IN CFS Area (OH Part)	C1b	6.83E+07	100
Cleveland-Akron-Canton, OH CFS Area	C1a	1.56E+09	88.85
Cleveland-Akron-Canton, OH CFS Area	C2	1.96E+08	11.15
Columbus-Marion-Zanesville, OH CFS Area	C1b	3.77E+08	100
Dayton-Springfield-Sidney, OH CFS Area	C1b	1.76E+08	100
Detroit-Warren-Ann Arbor, MI CFS Area	C1a	4.64E+07	8.19

Table 23: Region Cost Saving Summary Cases

FAF4	**Case**	**Savings (USD)**	**FAF4 Share**
Detroit-Warren-Ann Arbor, MI CFS Area	C1b	5.20E+08	91.81
Fort Wayne-Huntington-Auburn, IN CFS Area	C1b	6.00E+07	100
Grand Rapids-Wyoming-Muskegon, MI CFS Area	C1b	3.33E+06	100
Greensboro-Winston-Salem-High Point, NC CFS Area	C1a	0.00E+00	0
Greensboro-Winston-Salem-High Point, NC CFS Area	C1b	1.29E+08	100
Greenville-Spartanburg-Anderson, SC CFS Area	C1a	0.00E+00	0
Greenville-Spartanburg-Anderson, SC CFS Area	C1b	1.04E+08	100
Hartford-West Hartford-East Hartford, CT CFS Area	C1a	5.35E+08	98.59
Hartford-West Hartford-East Hartford, CT CFS Area	C2	7.66E+06	1.41
Indianapolis-Carmel-Muncie, IN CFS Area	C1b	3.93E+07	100
Jacksonville-St. Marys-Palatka, FL-GA CFS Area (FL Part)	C1a	0.00E+00	0
Jacksonville-St. Marys-Palatka, FL-GA CFS Area (FL Part)	C1b	7.92E+05	100
Knoxville-Morristown-Sevierville, TN CFS Area	C1a	0.00E+00	0
Knoxville-Morristown-Sevierville, TN CFS Area	C1b	1.32E+08	100
Louisville/Jefferson County-Elizabethtown-Madison, KY-IN CFS Area (KY Part)	C1a	0.00E+00	0
Louisville/Jefferson County-Elizabethtown-Madison, KY-IN CFS Area (KY Part)	C1b	1.90E+07	100
Memphis, TN-MS-AR CFS Area (TN Part)	C1a	0.00E+00	0
Memphis, TN-MS-AR CFS Area (TN Part)	C1b	6.95E+05	100
Miami-Fort Lauderdale-Port St. Lucie, FL CFS Area	C1a	0.00E+00	0
Miami-Fort Lauderdale-Port St. Lucie, FL CFS Area	C1b	3.48E+06	100
Mobile-Daphne-Fairhope, AL CFS Area	C1a	0.00E+00	0
Mobile-Daphne-Fairhope, AL CFS Area	C1b	7.87E+05	100
Nashville-Davidson-Murfreesboro, TN CFS Area	C1a	0.00E+00	0
Nashville-Davidson-Murfreesboro, TN CFS Area	C1b	1.30E+06	100
New York-Newark, NY-NJ-CT-PA CFS Area (CT Part)	C1a	8.87E+08	98.67
New York-Newark, NY-NJ-CT-PA CFS Area (CT Part)	C2	1.20E+07	1.33
New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part)	C1a	1.02E+10	88.28
New York-Newark, NY-NJ-CT-PA CFS Area (NJ Part)	C2	1.36E+09	11.72
New York-Newark, NY-NJ-CT-PA CFS Area (NY Part)	C1a	8.07E+09	98.19
New York-Newark, NY-NJ-CT-PA CFS Area (NY Part)	C2	1.48E+08	1.81
New York-Newark, NY-NJ-CT-PA CFS Area (PA Part)	C1a	5.56E+08	99.29
New York-Newark, NY-NJ-CT-PA CFS Area (PA Part)	C2	3.97E+06	0.71
Orlando-Deltona-Daytona Beach, FL CFS Area	C1a	0.00E+00	0
Orlando-Deltona-Daytona Beach, FL CFS Area	C1b	1.63E+06	100

Table 23: Region Cost Saving Summary Cases

FAF4	**Case**	**Savings (USD)**	**FAF4 Share**
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (DE Part)	C1a	9.06E+07	90.51
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (DE Part)	C1b	8.93E+06	8.92
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (DE Part)	C2	5.62E+05	0.56
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (NJ Part)	C1a	2.30E+09	92.22
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (NJ Part)	C1b	1.69E+08	6.77
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (NJ Part)	C2	2.52E+07	1.01
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (PA Part)	C1a	5.86E+08	32.29
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (PA Part)	C1b	1.22E+09	67.19
Philadelphia-Reading-Camden, PA-NJ-DE-MD CFS Area (PA Part)	C2	9.48E+06	0.52
Pittsburgh-New Castle-Weirton, PA-OH-WV CFS Area (PA Part)	C1a	9.72E+08	100
Raleigh-Durham-Chapel Hill, NC CFS Area	C1a	0.00E+00	0
Raleigh-Durham-Chapel Hill, NC CFS Area	C1b	1.67E+08	100
Remainder of Alabama	C1a	0.00E+00	0
Remainder of Alabama	C1b	3.72E+06	100
Remainder of Connecticut	C1a	1.42E+08	83.94
Remainder of Connecticut	C2	2.73E+07	16.06
Remainder of Delaware	C1a	2.67E+07	90.51
Remainder of Delaware	C1b	2.64E+06	8.92
Remainder of Delaware	C2	1.66E+05	0.56
Remainder of Florida	C1a	0.00E+00	0
Remainder of Florida	C1b	3.12E+06	100
Remainder of Georgia	C1a	0.00E+00	0
Remainder of Georgia	C1b	3.21E+06	100
Remainder of Indiana	C1b	4.62E+07	100
Remainder of Kentucky	C1a	0.00E+00	0
Remainder of Kentucky	C1b	3.68E+06	100
Remainder of Maine	C1a	1.79E+08	94.83
Remainder of Maine	C2	9.77E+06	5.17
Remainder of Maryland	C1a	2.12E+08	86.08

Table 23: Region Cost Saving Summary Cases

FAF4	**Case**	**Savings (USD)**	**FAF4 Share**
Remainder of Maryland	C1b	3.28E+07	13.3
Remainder of Maryland	C2	1.53E+06	0.62
Remainder of Massachusetts	C1a	2.30E+08	81.08
Remainder of Massachusetts	C2	5.38E+07	18.92
Remainder of Michigan	C1a	8.89E+06	3.85
Remainder of Michigan	C1b	2.08E+08	89.81
Remainder of Michigan	C2	1.47E+07	6.34
Remainder of New Hampshire	C1a	7.21E+07	76.41
Remainder of New Hampshire	C2	2.23E+07	23.59
Remainder of New York	C1a	7.48E+08	60.74
Remainder of New York	C1b	4.83E+08	39.26
Remainder of North Carolina	C1a	0.00E+00	0
Remainder of North Carolina	C1b	3.22E+08	100
Remainder of Ohio	C1a	8.77E+07	9.51
Remainder of Ohio	C1b	8.34E+08	90.49
Remainder of Pennsylvania	C1a	1.60E+09	89.24
Remainder of Pennsylvania	C2	1.93E+08	10.76
Remainder of South Carolina	C1a	0.00E+00	0
Remainder of South Carolina	C1b	1.99E+08	100
Remainder of Tennessee	C1a	0.00E+00	0
Remainder of Tennessee	C1b	1.67E+06	100
Remainder of Vermont	C1a	3.95E+07	76.68
Remainder of Vermont	C2	1.20E+07	23.32
Remainder of Virginia	C1a	0.00E+00	0
Remainder of Virginia	C1b	1.49E+08	100
Remainder of West Virginia	C1a	4.50E+08	95.24
Remainder of West Virginia	C1b	2.25E+07	4.76
Richmond, VA CFS Area	C1a	0.00E+00	0
Richmond, VA CFS Area	C1b	2.30E+08	100
Rochester-Batavia-Seneca Falls, NY CFS Area	C1a	4.76E+08	95.71
Rochester-Batavia-Seneca Falls, NY CFS Area	C2	2.13E+07	4.29
Tampa-St. Petersburg-Clearwater, FL CFS Area	C1a	0.00E+00	0
Tampa-St. Petersburg-Clearwater, FL CFS Area	C1b	1.55E+06	100
Virginia Beach-Norfolk, VA-NC CFS Area (VA Part)	C1a	0.00E+00	0
Virginia Beach-Norfolk, VA-NC CFS Area (VA Part)	C1b	5.33E+08	100
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (DC Part)	C1a	1.76E+07	98.01

Table 23: Region Cost Saving Summary Cases

FAF4	**Case**	**Savings (USD)**	**FAF4 Share**
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (DC Part)	C1b	3.57E+05	1.99
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (MD Part)	C1a	7.72E+08	90.95
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (MD Part)	C1b	7.68E+07	9.05
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (VA Part)	C1a	0.00E+00	0
Washington-Arlington-Alexandria, DC-VA-MD-WV CFS Area (VA Part)	C1b	1.75E+08	100