Unconventional Protectionism in Containerized Shipping

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Abstract

Containerized shipping operates similarly to a bus system, where containerized shipping relies on repeated service loops that must balance reusable equipment across locations. To ensure transport equipment availability, vessel owners reposition empty containers on low-volume voyages, from net importer origins to net exporter destinations. I provide novel evidence that aggregate US container traffic is approximately balanced only when accounting for empty container repositioning. Motivated by the Ocean Shipping Reform Act of 2022, I estimate a structural model to capture the effects of a US restriction on empty container outflows in favor of stimulating US exports. Although successful in stimulating exports, intervention backfires through elevated import prices, lower transport capacity, and reduced overall trade.

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1 Introduction

International trade relies heavily on transport systems that repeatedly redeploy physical equipment across locations. In maritime shipping, standardized containers must be continuously reused and repositioned to sustain global commerce. Containerized shipping alone accounts for roughly two-thirds of world cargo trade by value (Notteboom et al., 2022). Given that trade volumes are rarely balanced across countries, ocean carriers must regularly reposition empty containers back to net exporter countries to maintain future service. This practice accounts for roughly 20% of global container movements and 15% of fleet costs (Rodrigue, 2020). Although logistics studies have long recognized the operational costs of repositioning (Crainic et al., 1993; Song, 2021), much less is known about how this inventory-management problem influences transportation prices and broader international trade outcomes.

These considerations have become increasingly policy-relevant. Recent interventions have extended beyond conventional tariffs toward logistics-oriented trade measures, including restrictions on empty-container outflows under the Ocean Shipping Reform Act of 2022 (OSRA22) and proposed U.S. port fees on foreign-built vessels (Executive Office of the POTUS, 2026). Such policies operate by constraining the transport systems through which trade is conducted, rather than by directly taxing goods flows, and are relevant to modes of transport beyond maritime commerce.

In this paper, I examine container repositioning under round-trip trade and quantitatively evaluate how restrictions on empty-container outflows may influence U.S. trade outcomes. To study these effects, I build a quantitative model of round-trip trade based on Armington (1969), featuring endogenous transport costs and trade imbalances. Exporters face domestic production costs and freight rates charged by transport operators maintaining bilateral services. Transport service prices are determined competitively and reflect both loaded and empty container handling costs. In extensions to the baseline bilateral round trip framework, I allow for scale economies, multi-stop vessel rotations, and indirect routing across interconnected shipping lanes. These richer environments preserve the core comparative statics of the model.

I aggregate novel port-level loaded and empty container traffic data to capture the net-importer position of the United States relative to the Rest of the World (RoW). Since these records measure port throughput rather than complete foreign origin-destination routes, the evidence is interpreted at an aggregate U.S.–RoW level. I use these data to assess key implications of the round-trip framework and document three descriptive facts: (i) empty-container outflows from a net importer rise as directional shipping imbalances expand; (ii) aggregate inbound and outbound container flows are approximately balanced only once empty repositioning is included; and (iii) port size helps determine balancing roles within the national network, with large gateways such as Los Angeles and New York exhibiting persistent net inflows of containers, while many mid-sized ports are net outflow locations.

To conduct the quantitative policy analysis, I combine port-level container traffic records with U.S. Census data on monthly bilateral containerized trade by product, value, and weight. I estimate the baseline model in two stages. First, I recover bilateral loaded-container flows by estimating product-specific loading factors that map HS2 shipment weights into loaded container usage. These implied route-level flows align closely with external UNCTAD measures of East Asia–North America and Europe–North America traffic. Second, I use an exactly identified method-of-moments calibration to recover route-specific demand parameters and the per-unit costs of handling loaded and empty containers. Remaining parameters are calibrated using public data from the ILO, OECD, and World Bank.

The resulting parameter estimates are economically plausible and consistent with observed industry patterns. Depending on the route, estimated empty-container handling costs range from 14.9% to 21.3% of fleet-management costs, close to the 15% benchmark reported by Rodrigue (2020). Implied freight rates are also systematically higher on the high-volume leg of an imbalanced round trip, consistent with the directional pricing patterns documented by Hummels et al. (2009).

To capture the economic intent of OSRA22, I study a stylized empty-container outflow (ECO) quota that reallocates vessel capacity toward U.S. exporters. I consider a moderate regime targeting the historical benchmark in which empty containers account for 40% of total U.S. container outflows. While restricting the return of empty equipment expands selected export margins, it conflicts with broader welfare objectives once general-equilibrium shipping responses are taken into account. Round-trip shipping capacity falls by 18.4% and containerized imports decline by 17.1%, which leads to the value of containerized trade declining by 8.2%.

This paper contributes along several dimensions. It assembles novel data on loaded and empty container traffic to provide some of the first systematic empirical evidence on how container repositioning conditions relate to trade outcomes. It also develops a micro-founded model linking reusable transport equipment, endogenous freight rates, and trade imbalances, allowing logistical frictions to be studied within a quantitative trade framework. Lastly, the model provides a tractable platform for evaluating emerging forms of logistics-based protectionism that operate through transport capacity rather than conventional tariffs. Together, the paper combines new data, theory, and policy quantification to study an economically important margin of international trade that is largely absent from existing trade models. These contributions connect to several strands of the literature.

First, this paper adds to studies of endogenous trade costs and maritime transport. Transport costs represent an increasingly prominent factor in determining overall trade costs. Hummels (2007) finds that for every $1 exporters paid in tariff duties to send goods to the US, $9 was paid in transportation costs. Although earlier studies used ad hoc transport costs,[1] more recent theoretical frameworks use a variety of endogenous approaches (Atkin and Donaldson, 2015; Irarrazabal et al., 2015; Asturias, 2020; Hayakawa et al., 2020; Bonadio, 2024; Allen and Arkolakis, 2022; Wong and Fuchs, 2022; Ardelean and Lugovskyy, 2023; Ignatenko, 2024). The paper is most closely related to Brancaccio et al. (2020) and Wong (2022). As in Brancaccio et al. (2020), directional imbalances on transport routes affect trade costs through backhaul utilization. My setting differs by focusing on reusable container equipment and the empty-repositioning margin directly. Relative to Wong (2022), who studies freight-rate asymmetries in containerized trade, I explicitly model loaded and empty container inputs and use newly assembled empty-container traffic data to quantify the equipment-repositioning margin.

Technological and logistical innovations also play important roles in influencing trade outcomes (Bernhofen et al., 2016; Brooks et al., 2021; Ulltveit-Moe et al., 2019; Carreras-Valle, 2022). Ganapati et al. (2024) provides evidence of logistical hubs known as *entrepôts* fostering advancements in vessel technology and size, which lowered transport costs. Combining port-level container traffic data with bilateral containerized trade records, I demonstrate a joint dependency on the logistical practice of empty container repositioning on both legs of round trip services between the US and the rest of the world. I find that limitations on this practice may undermine the benefits of containerization. I also provide a means of estimating container flows by trade partner and add to studies on product-level elasticities in trade (Shapiro, 2016; Steinwender, 2018). I capture product-level elasticities of loaded container flows with respect to goods weight, coined as 'loading factors', which may assist in broadening the scope to which further studies of maritime transport can develop.

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[1] Transport costs are often treated as an exogenous model primitive, commonly referred to as an iceberg cost, which represents a fixed percentage of value attrition while a good is in transit (Samuelson, 1952).

I also contribute to the literature on trade imbalances by emphasizing the role of transport frictions in sustaining bilateral asymmetries. Conventionally, trade imbalances are attributed to structural factors such as residual trade costs (Reyes-Heroles, 2017), policy-driven reserve accumulation (Dooley et al., 2003), labor market asymmetries, and sectoral productivity differences (Obstfeld and Rogoff, 2005; Kehoe et al., 2018; Dix-Carneiro et al., 2023). Yet, even in the presence of such forces, logistical frictions and transport costs play a key role in shaping the extent to which imbalances manifest in goods flows (Alessandria et al., 2010). I highlight how lower costs of repositioning empty containers enable transport operators to sustain larger trade volume asymmetries on shipping routes. When restricted, imbalances become costlier to service, resulting in higher transport prices, reduced trade flows, and concentrated welfare losses, particularly on highly asymmetric lanes (e.g. US-China).

Furthermore, this paper contributes to research on resurgent trade protectionism. Such policies are often shaped by the interests of domestic constituencies and organized producer groups (Ludema et al., 2018; Grossman and Helpman, 2021; Bombardini et al., 2023). While protectionist interventions frequently generate welfare losses (Fan et al., 2015; Fajgelbaum et al., 2020; Bown, 2021; Fajgelbaum and Khandelwal, 2022), they may also place favored sectors on more advantageous growth paths (Juhász, 2018). Most of this literature has focused on demand-side interventions, such as tariffs and related import restrictions (Broda et al., 2008; Grundke and Moser, 2019; Alessandria et al., 2025). More recently, policymakers have also turned toward logistics-oriented trade measures, including proposed U.S. port fees on foreign-built vessels (Executive Office of the POTUS, 2026). This paper studies one such supply-side intervention: policies that restrict the use and reuse of transport equipment, motivated by OSRA22. I show that these measures disproportionately burden net exporters, especially those relying more heavily on empty-container repositioning, and therefore function as a targeted and potentially discriminatory barrier to trade. The paper highlights a novel protectionist margin that may raise concerns for institutions such as the WTO that seek to discipline trade-distorting policies.

Lastly, this paper adds to theoretical representations of round trip transport services, commonly featured in airline, rail, and maritime sectors. Given bilateral trade volume imbalances, shipping capacity on the lower volume ‘backhaul’ route is underutilized (Tanaka and Tsubota, 2017; Behrens et al., 2018). In canonical round-trip models without additional frictions, the ‘backhaul’ freight rate can collapse to zero under perfect competition and perfect information. Demirel et al. (2010) and Wong (2022) address this deviation from reality by either (i) forcing balanced trade flows across round trips, or (ii) introducing imperfect information and a matching process. Ishikawa and Tarui (2018) solves for positive bilateral freight rates by introducing imperfect competition. I account for the status of physical equipment inputs in a joint profit function of round trip transport services. To ensure the continued service of the high-volume leg of an imbalanced round trip, a transport operator repositions empties. The marginal revenue of shipping an additional loaded container on the high-volume leg is equal to the cost of loaded handling plus the cost of returning one empty container. In contrast, transporting an additional loaded unit on the low-volume leg occupies an existing empty, resulting in a freight rate equal to the loaded handling cost less the cost of returning an empty unit. This yields positive bilateral freight rates, where the low-volume route maintains a relatively lower price, as predicted in Hummels et al. (2009). This pricing scheme under asymmetric volumes relates closely to peak-load pricing strategies on passenger flights and dynamic toll lanes (Williamson, 1966; Cook and Li, 2024).

The remainder of the paper proceeds as follows. The next section details the factors that contribute to empty container repositioning and outlines a partial equilibrium model of containerized trade. Section 3 describes the novel data I rely upon, and Section 4 presents stylized facts of containerized trade and empty container repositioning. In Section 5, I calibrate and estimate the exogenous parameters of the empty container model and consider the counterfactual effects of government intervention that limits US outflows of empty containers. Section 6 concludes.

2 Model

In this section, I incorporate empty container repositioning in an augmented Armington model based on Hummels et al. (2009) and Wong (2022). The bilateral route should be interpreted as a reduced-form lane-level equipment-balance condition rather than a literal vessel itinerary. Actual liner services often involve multi-port rotations, and containers may be reused across intermediate ports before returning to net-exporter locations. The baseline abstracts from these itinerary details to obtain a tractable mapping between directional trade imbalances, empty repositioning, and freight-rate asymmetries. Appendix Section III shows that allowing indirect routing dampens but does not reverse the central comparative statics. Endogenous transport costs are a function of per-unit loaded and empty container handling costs. I first detail key logistical facts about shipping, then outline my associated assumptions and solve the model. Lastly, I establish a set of comparative statics that detail how trade imbalances emerge. I demonstrate that the cost of empty repositioning underpins the extent to which asymmetries in trade flows can form between countries. For a given round trip route, as empty handling costs falls, bilateral freight rates contribute to greater skewness in trade flows and increased bilateral containerized trade volumes.

2.1 Background

Container unit standardization was the key development that led to the modern-day scale of intermodal transportation. These efforts resulted in a flexible, harmonized system in which transport equipment could be freely exchanged back and forth within a given round trip. Although empty repositioning has been a long-held practice, many ask why operators coordinate in this manner. Bilateral transport service demand within a given round trip can differ, leading to net exporters shipping more loaded container units to a given destination than return loaded from the net importer. To meet exporters' needs in both locations, vessels transport empty units on the backhaul (lower volume) leg of a round trip. This behavior reflects an inventory management problem in which a cost-minimizing assignment of container capacity and flows must be determined.[2] The existence of the backhaul problem itself is not a form of market failure and this practice is not limited to periods of elevated port congestion.

Lee and Song (2017) highlights two considerations that transport operators face under imbalanced round trips: (i) a quantity decision where firms decide how many empties to store at each port, and how many to move between ports, and (ii) a cost estimation of empty repositioning, which affects the freight rate. Network flow models specify the number of empty containers to be relocated across nodes to satisfy equipment-balance conditions at the network level (Song and Dong, 2015). Additionally, uncertainties are considered to produce decision-making rules that dynamically determine the amount of empties in and out of a node. I feature empty container costs in the freight rate setting and enforce a balanced container flow constraint between nodes. However, I do not feature decision-making for short-term uncertainty.

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[2] As Lee and Song (2017) highlights, empty container repositioning functions similarly to conventional manufacturing logistics in which firms strategically relocate their inventory to meet consumer demand. In the case of containerized round trip shipping, exporters consume transport services from transport operators, and container units are redistributed to be readily available for further shipping service demand. When volumes of service demand differ on these continuous loops of transportation, firms strategically relocate empty container units to sustain the service of their larger export volume destination.

2.2 Assumptions

I consider an international economy of round trip containerized trade that features J heterogeneous countries, each producing a unique variety of a tradeable good. The term $\overleftrightarrow{ij}$ denotes a round trip that services trade between countries i and j. Geographically immobile consumers in country j are endowed with one unit of labor that is supplied elastically and exhibit a love of variety across consumable goods. A consumer at location j is assumed to maximize a quasi-linear utility function:

$$\max_{\{l_{j0},\ldots,l_{ij}\}} U_j = l_{j0} + \sum_{i=1}^{M} a_{ij} l_{ij}^{(\epsilon-1)/\epsilon}, \quad \epsilon > 1, \tag{1}$$

where l_{j0} represents the quantity of the numeraire good consumed in country j and l_{ij} represents the quantity of a tradeable variety sourced from country i.[3] Heterogeneous countries maintain route-specific preference parameters, a_{ij}, for each tradeable variety. A single unit of a good requires one unit of transport equipment. Therefore, l_{ji} is equivalent to the number of loaded containers shipped from j to i. The number of empty containers on leg ji is e_{ji}. The price elasticity of demand, ϵ, is common across varieties and routes. Producers are perfectly competitive and produce a variety j using labor. I assume goods' prices from i to j increase through the domestic wage, w_i, the ad valorem tariff of the given ij leg, τ_{ij}, and the per-container freight rate, T_{ij}. Holmes and Singer (2018) highlights an indivisibility of transport costs due to per-container freight rates not varying based on variation in the usage of containers' cubic volume capacity. While this additive representation of freight rates is widely accepted (Martin, 2012; Ardelean et al., 2022), there is nuance to how tariff rates are applied.[4]

$$p_{ij} = w_i \tau_{ij} + T_{ij} \tag{2}$$

Transport operators are perfectly competitive and service a given bilateral trade route, $\overleftrightarrow{ij}$. The profit maximization problem for servicing round trip $\overleftrightarrow{ij}$ is a joint-profit function that considers the optimal bundle of container inputs. This is a variation of Behrens and Picard (2011), in which I add a balanced container flow constraint.

$$\max_{\{l_{ij},l_{ji},e_{ij},e_{ji}\}} \pi_{\overleftrightarrow{ij}} = T_{ij} l_{ij} + T_{ji} l_{ji} - c_{ij} l_{ij} - c_{ji} l_{ji} - r_{ij} e_{ij} + r_{ji} e_{ji} \tag{3}$$
$$\text{s.t. } l_{ij} + e_{ij} = l_{ji} + e_{ji}$$

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[3] The numeraire good is traded at no cost and maintains a unit price of 1.

[4] In the US, Canada, and Japan, tariffs are applied to the 'FOB' value of goods, which excludes the costs, insurance, and freight elements of imports. $p_{ij} = \tau_{ij} (w_i + T_{ij})$ would be a more appropriate representation of prices outside of the US, Canada, and Japan. The results of this paper are not qualitatively sensitive to either specification.

Revenue generated from servicing route $\overset{\leftrightarrow}{ij}$ is the sum of each leg's respective freight rate times the loaded container quantity. Costs are determined by inputs used to provide service. Loaded and empty container handling costs are represented by the set $\{c_{ij}, c_{ji}, r_{ij}, r_{ji}\}$.[5] I assume that empty containers are cheaper to handle.[6] Bilateral container unit flows are balanced, implying vessels operate at full capacity. Next, I depict profit maximization under *weakly* imbalanced trade. This model nests the case of balanced trade featured in Wong (2022), as demonstrated in the system of equations outlined in Online Appendix II.

2.3 Weakly Imbalanced Trade

Suppose country j is a weak net importer of route $\overset{\leftrightarrow}{ij}$, where $l_{ij} \geq l_{ji}$. This leads to an empty repositioning problem, and the balanced container flow constraint becomes $l_{ij} = l_{ji} + e_{ji}$, where service capacity is pinned down by $\max\{l_{ij}, l_{ji}\}$. This is consistent with other imbalanced trade models under a round trip setting (Ishikawa and Tarui, 2018). To ensure positive bilateral freight rates under imbalanced trade, I assume that the per-unit shipment cost of empties is cheaper than loaded handling on every route: $c_{ji} > r_{ji} \; \forall \; ji$. The profit maximization problem is expressed as

$$\max_{\{l_{ij}, l_{ji}, e_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij} l_{ij} + T_{ji} l_{ji} - c_{ij} l_{ij} - c_{ji} l_{ji} - r_{ji} e_{ji} \tag{4}$$

$$\text{s.t. } e_{ji} = l_{ij} - l_{ji}$$

Upon substituting the balanced container constraint into the profit maximization problem, freight rates for both legs of a given round trip $\overset{\leftrightarrow}{ij}$ are determined. Due to the price-taking nature of this perfectly competitive transport operator, prices are underpinned by the marginal costs of container redistribution.[7]

$$T^*_{ij} = c_{ij} + r_{ji} \;, \; T^*_{ji} = c_{ji} - r_{ji} \tag{5}$$

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[5] I attribute container handling costs to the transport operator which, on average, represents 15% of fleet management costs on empty repositioning (Notteboom et al., 2022).

[6] Online Appendix I considers homogeneous input prices across container units. Similarly to Behrens and Picard (2011), this specification yields zero freight rates on low-volume legs of round trip trade. Given that I do not observe zero empty container flows, nor zero freight rates across observed data, I conclude that there must be differences in input prices across containers which vary by loaded status.

[7] Before 2020 Q3, financial records of the global containerized shipping industry reported persistent near-zero net income. See https://capitallinkshipping.com/category/contributors/john-mccown-container-report/ for further details. Last accessed as of 02/10/2025.

These first-order conditions intuitively state that the marginal benefit of an additional loaded container on the larger volume leg, from net exporter i to net importer j, is equal to the direct per unit shipping cost, c_{ij}, and the cost of an additional empty container on the return trip, r_{ji}. An additional loaded container transported from j to i represents one less empty on route $\overset{\leftrightarrow}{ij}$, which implies the added cost of c_{ji} being partially compensated for by a cost reduction of r_{ji}. Expressions for these bilateral freight rates can be substituted into Eq. (2).

$$p^*_{ij} = w_i\tau_{ij} + c_{ij} + r_{ji}, \qquad p^*_{ji} = w_j\tau_{ji} + c_{ji} - r_{ji} \tag{6}$$

Inserting Eq. (7) into the demand function for imported varieties,

$$\begin{aligned} l^*_{ij} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}(w_i\tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} \\ l^*_{ji} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\right)^{-\epsilon}(w_j\tau_{ji} + c_{ji} - r_{ji})^{-\epsilon}, \end{aligned} \tag{7}$$

the net difference in flows determines the quantity of empty container flow and the flow direction. In this case $l^*_{ij} = \max\{l_{ij}, l_{ji}\} \geq l^*_{ji}$, which implies that empties will travel on the lower volume backhaul route ji.

$$e^*_{ji} = \left(\frac{\epsilon}{\epsilon-1}\right)^{-\epsilon}\left(\frac{1}{a_{ij}}^{-\epsilon}(w_i\tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} - \frac{1}{a_{ji}}^{-\epsilon}(w_j\tau_{ji} + c_{ij} - r_{ji})^{-\epsilon}\right) \tag{8}$$

The resulting equilibrium trade quantities, $\{l_{ij}, l_{ji}\}$, and values, $\{X_{ij}, X_{ji}\}$, on route $\overset{\leftrightarrow}{ij}$ are decreasing in the marginal cost of loaded container transport, local wages, and import tariffs imposed by the destination country.

$$\begin{aligned} X^*_{ij} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}(w_i\tau_{ij} + c_{ij} + r_{ji})^{1-\epsilon} \\ X^*_{ji} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\right)^{-\epsilon}(w_j\tau_{ji} + c_{ji} - r_{ji})^{1-\epsilon} \end{aligned} \tag{9}$$

However, variation in empty container handling costs, r_{ji}, will have counteracting effects on outcome variables for a given round trip, highlighting a round trip effect in the model. For example, suppose the cost of empty outflows from country j rises. Not only does this stimulate j's exports, as existing cargo space on leg ji is reallocated from empties, but in addition, the transport capacity of route $\overset{\leftrightarrow}{ij}$, reflected by l^*_{ij}, declines. Transport services on route $\overset{\leftrightarrow}{ij}$ decline due to the cost of maintaining imbalanced container flows.

2.4 Comparative Statics

Consider first a set of demand shocks to consumer preferences $\{a_{ij}, a_{ji}\}$ and import tariff adjustments $\{\tau_{ij}, \tau_{ji}\}$. In each case, a marginal change implies the following adjustments to the trade outcomes for route $\overset{\leftrightarrow}{ij}$. Assuming $\epsilon > 1$:

$$\frac{\partial T^*_{ij}}{\partial \tau_{ij}} = 0 \quad , \quad \frac{\partial T^*_{ji}}{\partial \tau_{ij}} = 0 \quad , \qquad \frac{\partial p^*_{ij}}{\partial \tau_{ij}} = w_i > 0 \quad , \quad \frac{\partial p^*_{ji}}{\partial \tau_{ij}} = 0$$

$$\frac{\partial X^*_{ij}}{\partial \tau_{ij}} = (1-\epsilon) w_i \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}} \right)^{-\epsilon} (w_i \tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} < 0 \quad , \quad \frac{\partial X^*_{ji}}{\partial \tau_{ij}} = 0$$

$$\frac{\partial e^*_{ji}}{\partial \tau_{ij}} = -\epsilon w_i \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}} \right)^{-\epsilon} (w_i \tau_{ij} + c_{ji} + r_{ji})^{-(\epsilon+1)} < 0$$

A preference shock in country j for goods from country i would be represented by a_{ij} increasing. The outcome variables in this model adjust as follows.

$$\frac{\partial T^*_{ij}}{\partial a_{ij}} = 0 \quad , \quad \frac{\partial T^*_{ji}}{\partial a_{ij}} = 0 \quad , \qquad \frac{\partial p^*_{ij}}{\partial a_{ij}} = 0 \quad , \quad \frac{\partial p^*_{ji}}{\partial a_{ij}} = 0$$

$$\frac{\partial X^*_{ij}}{\partial a_{ij}} = \epsilon \frac{\epsilon - 1}{\epsilon} \left(\frac{\epsilon - 1}{\epsilon} a_{ij} \right)^{\epsilon - 1} (w_i \tau_{ij} + c_{ij} + r_{ji})^{1-\epsilon} > 0 \quad , \quad \frac{\partial X^*_{ji}}{\partial a_{ij}} = 0$$

$$\frac{\partial e^*_{ji}}{\partial a_{ij}} = \epsilon \frac{\epsilon - 1}{\epsilon} \left(\frac{\epsilon - 1}{\epsilon} a_{ij} \right)^{\epsilon - 1} (w_i \tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} > 0$$

Since these are perfectly competitive firms providing transport services, quantity supplied and freight rates are unresponsive to demand-side adjustments. However, when the underlying costs of these services adjust, the corresponding freight rates charged will be adjusted uniformly. Endogenous transport costs are a linear function of the underlying costs of shipping the required container inputs. Suppose the underlying cost of repositioning empty containers increases. This will make the existing trade balance less viable to sustain. In response, firms widen the freight rate 'gap' between ij and ji, where the net exporter countries observe freight rates of outgoing goods increase and net importer countries see freight rates of outgoing goods decline. This results in the trade balance narrowing and the 'backhaul' problem shrinking in scale.

$$\frac{\partial T^*_{ij}}{\partial r_{ji}} = \frac{\partial p^*_{ij}}{\partial r_{ji}} \quad > 0 \quad , \frac{\partial T^*_{ji}}{\partial r_{ji}} = \frac{\partial p^*_{ji}}{\partial r_{ji}} \quad < 0$$

$$\frac{\partial X^*_{ij}}{\partial r_{ji}} = (1-\epsilon) \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}} \right)^{-\epsilon} (w_i \tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} < 0 \quad ,$$

$$
\begin{aligned}
\frac{\partial X_{ji}^*}{\partial r_{ji}} &= (\epsilon - 1)\left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ji}}\right)^{-\epsilon}(w_j\tau_{ji} + c_{ji} - r_{ji})^{-\epsilon} \quad > 0, \\
\frac{\partial e_{ji}^*}{\partial r_{ji}} &= -\epsilon\left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ij}}\right)^{-\epsilon}(w_i\tau_{ij} + c_{ij} + r_{ji})^{-\epsilon-1} - \\
&\quad \epsilon\left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ji}}\right)^{-\epsilon}(w_j\tau_{ji} + c_{ji} - r_{ji})^{-\epsilon-1} < 0
\end{aligned}
$$

Proposition 1. Assuming competitive transport firms and imbalanced trade,

(i) When transport costs are endogenous and constrained under balanced container flows, an increase in the tariff rate of imports from i to a net importer country j, τ_{ij}, reduces the volume of the backhaul problem destined for the partner net exporter country i: $\frac{\partial e_{ji}^*}{\partial \tau_{ij}} < 0$

(ii) When transport costs are endogenous and constrained under balanced container flows, an increase in j's preferences for variety i, a_{ij}, increases the volume of the backhaul problem destined for the partner net exporter country i: $\frac{\partial e_{ji}^*}{\partial a_{ij}} > 0$

(iii) When transport costs are endogenous and constrained under balanced container flows, an increase in the per unit cost of empty container inputs, r_{ji}, reduces the volume of the backhaul problem, given that freight rates resultingly rise on the full route ij and lessen on the return route ji: $\frac{\partial T_{ij}^*}{\partial r_{ji}} > 0, \frac{\partial T_{ji}^*}{\partial r_{ji}} < 0, \frac{\partial e_{ji}^*}{\partial r_{ji}} < 0$

The relationship between the scale of empty container repositioning and trade balance skewness can be examined proportionally. These expressions simplify otherwise non-linear relationships between outcome variables to a reduced linear relationship. I represent empty repositioning with E_{ji}, empties as a percentage of total container outflows from net importer country j to net exporter i.

$$
E_{ji}^* = \frac{e_{ji}^*}{l_{ji}^* + e_{ji}^*} = 1 - \left(\frac{a_{ji}}{a_{ij}}\right)^{\epsilon}\left(\frac{w_i\tau_{ij} + c_{ij} + r_{ji}}{w_j\tau_{ji} + c_{ji} - r_{ji}}\right)^{\epsilon} \tag{10}
$$

Proposition 2. Assuming competitive transport firms and imbalanced trade,

(i) When transport costs are endogenous and constrained under balanced container flows, an increase in the tariff rate of imports from i to a net importer country j, τ_{ij}, reduces the scale of the backhaul problem destined for the partner net exporter country i: $\frac{\partial E_{ji}^*}{\partial \tau_{ij}} < 0$

(ii) When transport costs are endogenous and constrained under balanced container flows, an increase in j's preferences for variety i, a_{ij}, increases the scale of the backhaul problem destined for the partner net exporter country i: $\frac{\partial E_{ji}^*}{\partial a_{ij}} > 0$

(iii) When transport costs are endogenous and constrained under balanced container flows, an increase in the per unit cost of empty container inputs, $r_{\overset{\leftrightarrow}{ij}}$, reduces the scale of the backhaul problem, given that freight rates rise on the full route ij and lessen on the return route ji: $\frac{\partial T^*_{ij}}{\partial r_{ji}} > 0, \frac{\partial T^*_{ji}}{\partial r_{ji}} > 0, \frac{\partial E^*_{ji}}{\partial r_{ji}} < 0$

Examining the trade balance skew using an import-export ratio from j's view,

$$\frac{X^*_{ij}}{X^*_{ji}} = \left(\frac{a_{ji}}{a_{ij}}\right)^{-\epsilon} \left(\frac{w_i \tau_{ij} + c_{ij} + r_{ji}}{w_j \tau_{ji} + c_{ji} - r_{ji}}\right)^{1-\epsilon} \tag{11}$$

Using Eq. (10) and (11), I find that any exogenous shock to empty outflows will adjust the import-export ratio in the same sign direction for trade route ij. For example, should US preferences for goods from China rise, the existing trade deficit would increase $\left(\Delta \frac{X_{ij}}{X_{ji}} > 0\right)$ and the associated scale of empty container redistribution originating from the US would rise ($\Delta E_{ji} > 0$).[8]

The baseline model abstracts from several mechanisms emphasized in recent trade and transport research, such as scale economies, input-output linkages, overcapacity in shipping, network spillovers, and cost minimization across interlinked trade routes. While incorporating all such features lies beyond the scope of this paper, in Appendix Section III I extend the framework along two dimensions: (1) scale economies in containerized transport, and (2) indirect routing through third countries. These extensions validate the robustness of the core comparative statics. I find that while neither mechanism changes the direction of my model's comparative statics, scale economies amplify the effects of higher empty container costs and strategic indirect network responses dampen the effects of elevated empty container handling costs. This addresses the concern that bilateral round trips overstate empty repositioning by allowing third-country reuse of containers.

3 Data

The monthly data of the paper combines port-level US containerized trade and associated container traffic flows (empty and loaded units). Auxiliary tariff and wage data are used to calibrate key exogenous parameters, necessary for counterfactual analysis.

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[8] I test this identity empirically in Subsection 5.1 and find significance at a monthly frequency.

3.1 Containerized Goods

I use monthly trade data from the US Census Bureau, which details port-level flows of containerized goods by value, weight, and respective trade partner. From January 2003, these records detail commodity-specific trade flows at the six-digit Harmonized System (HS6) level. I form a balanced panel of the top 14 port locations for containerized trade flows.[9] In cases of port alliances, I assume that port infrastructure is jointly utilized between ports.[10]

3.2 Container Unit Traffic

I compile a panel of major U.S. container ports using monthly records obtained directly from port authorities. I specifically target ports by ranking them using containerized trade values to ensure high-return sites are prioritized. These data report twenty-foot equivalent unit (TEU) traffic in four series: (i) inbound loaded containers, (ii) outbound loaded containers, (iii) inbound empty containers, and (iv) outbound empty containers. A TEU is the standard industry measure of container capacity; for example, a 40-foot container is conventionally counted as two TEUs.

Unlike the containerized goods data used elsewhere in the paper, these port records do not identify the origin of inbound containers or the final destination of outbound containers. Instead, they measure container throughput at the reporting port. As a result, the data are well-suited to measuring aggregate port-level imbalances in loaded and empty equipment flows, which are central to the national US analysis. Given these measurement constraints, I treat the United States and the Rest of the World (RoW) as the two locations in the ij framework when constructing the descriptive moments, summed across ports.

To construct a balanced and representative panel, I retain twelve major ports with consistent monthly coverage from January 2012 through December 2024. These ports account for approximately 85% of national container throughput. Additional details on broader port time series are provided in Online Appendix IV.

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[9] These individual ports include New York (NY), Los Angeles (CA), Houston (TX), Long Beach (CA), Norfolk (VA), Savannah (GA), Charleston (SC), Oakland (CA), Newark (NJ), Seattle (WA), Tacoma (WA), Baltimore (MD), New Orleans (LA) and Jacksonville (FL).

[10] The ports of Seattle & Tacoma as well as New York & Newark are each combined into two unique port authorities, the NWSA and PANYNJ, respectively.

3.3 Auxiliary Data

For the quantitative exercises detailed in Section 5, I calibrate observable parameters of wages and tariffs through the use of monthly manufacturing wages and specific tariff rates data. Time series of monthly wages between 2012 and 2021 are sourced from the International Labor Organization (ILO), which specifies annual averages of manufacturing wages in USD value. To account for unreported wage values for specific years of the data, I use OECD annualized growth rates of average monthly manufacturing wages and infer the associated level amounts. I use the U.S. Bureau of Labor Statistics' "Consumer Price Index for All Urban Consumers", which excludes contributions made by food and energy, to deflate these series. I leverage the use of the UNCTAD Trade Analysis Information System (TRAINS) database for effective tariff rates on manufactured goods between the US and its trade partners.[11]

4 Descriptive Evidence

In this section, I present two stylized facts that test the validity of the balanced container flow constraint and the hypothesized negative relationship between the share of empty container outflows and the export-import value ratio of containerized goods. Additionally, I provide port-level evidence that suggests that the ports are interdependent in maintaining a nationally balanced set of container flows.

4.1 Empty Repositioning & Trade Balance Asymmetry

Stylized Fact 1. *At the aggregate U.S.–RoW level, a lower U.S. export-import ratio is associated with a larger share of U.S. outbound containers that are empty.*

Upon combining Eq.(10) and Eq.(11), the model implies this relationship at the route level. Given that foreign origins and destinations of empty containers are not observed, I test its aggregate analogue using U.S.–RoW flows. As US imports from a net exporter country increase, the asymmetry in trade volumes between these two countries grows - the logistical burden in servicing imbalanced trade has grown ($E_{ji} \uparrow$).

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[11] 'Manufactures' are a SITC 4 product group predefined on the World Integrated Trade Solution (WITS) platform of the World Bank.

$$E^*_{ji} = 1 - \left(\frac{X^*_{ji}}{X^*_{ij}}\right)\left(\frac{w_j\tau_{ji} + c_{ji} - r_{ji}}{w_i\tau_{ij} + c_{ij} + r_{ji}}\right) \tag{12}$$

Given that inbound container origins and outbound container destinations are not observed in the port data, country-pair empty shares cannot be measured directly. I therefore test this implication using monthly variation in aggregate trade and container flows between the United States (j) and the Rest of the World (i):[12]

$$E^*_{jit} = \alpha + \beta\left(\frac{X^*_{jit}}{X^*_{ijt}}\right) + \mu_{jit} \quad , \quad E^*_{ijt} = \alpha + \beta\left(\frac{X^*_{ijt}}{X^*_{jit}}\right) + \mu_{ijt}, \tag{13}$$

where $\beta < 0$ is my proposed null hypothesis. I use four measures of trade balance skew: the export-import ratio, $\frac{\text{Exports}}{\text{Imports}}$, a net-gross ratio featured in Brancaccio et al. (2020), $\frac{\text{Exports - Imports}}{\text{Total Trade}}$, and their respective opposites of $\frac{\text{Imports}}{\text{Exports}}$ and $\frac{\text{Imports - Exports}}{\text{Total Trade}}$ when addressing inflows of empties. As displayed in Table 1, a relatively smaller US trade deficit is associated with a lower scale of empty repositioning. In Table 2, using net-gross ratios, I find further support for the proposed relationship between prevailing trade imbalances and the scale of empty-container redistribution. Examining the robustness of these results in Online Appendix V, I find that variation in the weight of opposite-end trade flows is also predictive of adjustments in empty container repositioning. Additionally, upon disaggregating to *within-port* variation I find similar patterns of positive co-movement between trade flows and the opposite-end empty container repositioning problem.

The correlation between trade asymmetries and empty container shares is notably weaker for inbound flows than for outbound flows. This can be attributed to both data-driven and structural factors. First, the level and variation of inbound empty flows average 6.8% of total inbound containers, with low dispersion across ports and time. This limits statistical power and compresses the range of observed outcomes. Second, I assume static, cost-minimizing behavior, whereas inbound repositioning may reflect precautionary logistics, particularly for countries anticipating a surge in US export demand. This disconnect could attenuate the observed relationship.

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[12] $E^*_{\text{US,ROW},t}$ is measured as the share of outbound containers originating from US across P US ports that are empty: $\frac{\sum_p e_{p,ROW,t}}{\sum_p (l_{p,ROW,t} + e_{p,ROW,T})}$. In theory, this aggregate measure corresponds to a weighted average of country-specific empty shares: $\sum_i \omega_{US,i}\left(1 - \frac{X_{US,i}}{X_{i,US}} \cdot \frac{w_i\tau_{i,US} + c_{i,US} + r_{US,i}}{w_{US}\tau_{US,i} + c_{US,i} - rUS,i}\right)$, where $\omega_{US,i} = \frac{e_{US,i} + l_{US,i}}{\sum_i e_{US,i} + l_{US,i}}$. However, because I do not observe country-specific container volumes, I use the aggregate trade volume ratio $\frac{\sum_i X_{US,i}}{\sum_i X_{i,US}}$ on the right-hand side of the regression as a proxy.

Table. 1. Trade Flow Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows	Outbound		Inbound	
Model:	(1)	(2)	(3)	(4)
Export/Import (USD)	-1.013***			
	(0.0581)			
Export/Import (kg)		-0.4242***		
		(0.0287)		
Import/Export (USD)			-0.0237***	
			(0.0059)	
Import/Export (kg)				-0.0305***
				(0.0086)
Mean Dep. Var	46.5%		6.81%	
Mean Regressor	0.310	0.677	3.29	1.51
n-obs	156	156	156	156
Within R^2	0.54	0.64	0.24	0.13

Heteroskedasticity-consistent 'White' standard-errors. Codes: ***: 0.01, **: 0.05, *: 0.1. Examines variation empty containers as a share of total container outflows, given the variation in the skewness of the trade balance. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

Table. 2. Net-Gross Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows	Outbound		Inbound	
Model:	(1)	(2)	(3)	(4)
$\left(\frac{\text{Net Exports}}{\text{Gross Trade}}\right)^{\text{USD}}$	-0.8999***		0.2471***	
	(0.0602)		(0.0481)	
$\left(\frac{\text{Net Exports}}{\text{Gross Trade}}\right)^{\text{KG}}$		-0.6118***		0.1212***
		(0.0539)		(0.0330)
Mean Dep. Var	46.5%		6.81%	
Mean Regressor	-0.514	-0.172	-0.514	-0.172
n-obs	156	156	156	156
Within R^2	0.54	0.61	0.35	0.21

Heteroskedasticity-consistent 'White' standard-errors. Codes: ***: 0.01, **: 0.05, *: 0.1. Examines variation empty containers as a share of total container outflows, given the variation in the net-to-gross trade balance. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

4.2 Balanced Container Flows

Stylized Fact 2. *At the aggregate U.S.–RoW level, total inbound and outbound container flows are approximately balanced once empty containers are included.*

Upon aggregating observed container traffic flows across US ports, evidence suggests that national levels of total container inflows and outflows appear largely balanced, but only when including empty container repositioning in these totals (Figure 1). In Table 3, I regress inbound container traffic on outbound container traffic at the national level to address concerns about trends and seasonality in the data. Column 1 retains an intercept of zero, with total exchanges of containers functioning as a 1-for-1 system, even within a given month of containerized transport. In contrast, when focusing only on loaded container flows, a far more commonly reported measure of container traffic, this balance in the exchange of transport equipment is left completely obscured. These findings support the balanced container flow constraint, which underpins my partial equilibrium model of empty container repositioning.[13]

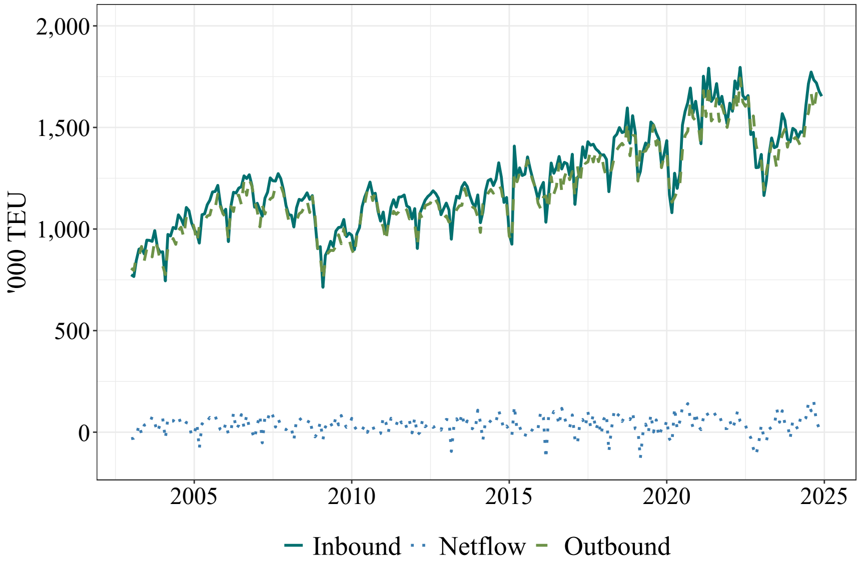

Figure 1. Inbound and Outbound Total Container Flows

Extending beyond monthly intervals, I find that container flows remain balanced. Although some larger aggregations of container flow do statistically deviate from the 1-to-1 ratio of balanced container flows, these deviations are low in power, only ranging between 1 to 2 percent in size.[14]

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[13] Using quarterly Eurostat data, I also document balanced container flows occurring in the European Union. Details are available in Appendix Section VIII.

[14] This is likely a symptom of my sample of ports being based on the larger ports in the US. As

Table. 3. Balanced National Container Flows

Dependent Variable: ln(Inbound Container Flows)			
Model:	Total (1)	Loaded (2)	Empty (3)
Intercept	-0.1033	22.73^{***}	18.44^{***}
	(0.2562)	(2.900)	(0.3518)
ln(Outbound Container Flows, Total)	1.008^{***}		
	(0.0178)		
ln(Outbound Container Flows, Loaded)		-0.6093^{***}	
		(0.2107)	
ln(Outbound Container Flows, Empty)			-0.4968^{***}
			(0.0258)
Observations	156	156	156
Within R^2	0.95	0.06	0.69

Heteroskedasticity-consistent 'White' standard-errors. Codes: ***: 0.01, **: 0.05, *: 0.1. Container flows inbound to the US are regressed on outbound container flows. Consistent with estimates using month and year fixed effects.

4.3 Port Heterogeneity

Stylized Fact 3. *A positive deviation in the total volume of container inflows and outflows of port p is correlated with a positive deviation from the net volume in container inflows less outflows of port p.*

Although total container flows – both loaded and empty containers – are balanced at the national level, patterns in port-level container flows highlight that large US ports function as net inflows of containers, while mid-tier ports act as net outflows. This suggests that interdependence exists across ports, which maintains balanced container flows at a national level. In Figure 2, I display annual net differences in total container flows by port for 2017 along with the geographic dispersion of these key entry and exit points for container equipment. These statuses are consistent across time. Los Angeles, Long Beach, PANYNJ, and NWSA act as net inflows whereas the remaining set of mid-tier ports are net outflows. As displayed in Figure 3, the total thruflow of loaded and empty containers at a given port is highly predictive of directional status.

This pattern likely relates to comparative advantages in handling vessels of varying sizes. Larger ports may attract net inflows due to their relatively higher efficiency in handling arriving goods (Blonigen and Wilson, 2008). This pattern may also be partly explained by the 'hub and spokes' mechanism in which larger vessels travel

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highlighted in the next section, although this data represents over 80% of container traffic in the US, the smaller ports that I exclude from my sample most likely function as net outflows of container units.

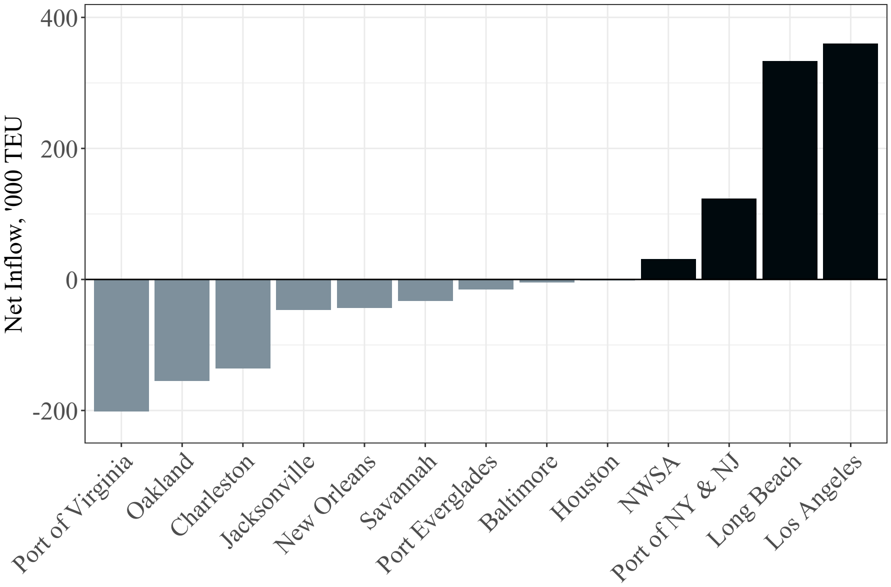

Figure 2. Port Specialization by Net Inflow Status (2017)

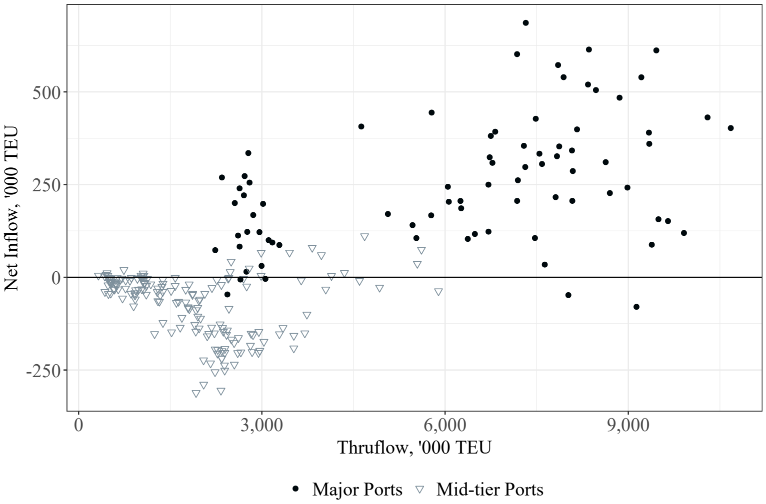

Figure 3. Port Specialization by Total Container Thruflow (2012-2021)

between port hubs to exploit lower per-unit transport costs (Ganapati et al., 2024). Upon examining average vessel sizes between these port groups, I find that larger vessels arrive at net inflow ports (Table 4). Additionally, the proximity-concentration argument would suggest that imports arriving in the US may chase high-density population centers such as California and New York (Ducruet et al., 2018).

Although it would be interesting to examine how closely model-implied freight rates reflect observed freight charges at the US port level, I neither model port-to-port transport service prices nor observe the freight rates necessary to perform such an exercise. Containerized port-level trade data, including separately measured freight and insurance charges, is available from 2009 onward (Schott, 2006) but limited to imports exclusively rather than bilateral trade flows.[15] Given that European import values of US containerized goods include the cost, insurance, and freight (CIF) associted with shipping, the net difference between these values expressed in USD and US containerized exports to the EU would, in theory, capture international freight margins. However, as Ardelean et al. (2022) shows, these differences are often negative or highly inconsistent, suggesting that CIF–FOB gaps would not reliably reflect actual freight or insurance costs.[16]

Given that national bilateral container flows are balanced, yet individual ports specialize, I suggest that container ports are interdependent in channeling flows of transport equipment. As highlighted in Wong and Fuchs (2022), shipments arriving at major ports see some portion of goods, along with intermodal transport equipment, be transported across the US hinterland. My findings suggest that many units of equipment depart from the US through alternative ports around the country, particularly through mid-tier-sized ports. Rather than treating each port's trade with the world as an isolated bilateral set of round trip trade routes, this container traffic data exhibits signs of a national-level round trip effect that permeates across ports. Containers are redistributed across US ports and collectively form a balanced container flow system necessary to support round trip containerized trade. This detail is key in motivating my country-level counterfactual analysis.

Table. 4. Average Containership Gross Tonnage by Port Size

Ports	2014	2015	2016	2017	2018	2019
Major Ports	31,558	32,990	34,790	36,569	38,141	39,241
Mid-tier Ports	26,564	27,999	29,639	31,637	32,784	33,407

Note: Reports the average gross tonnage, a nonlinear measure of a ship's overall internal volume, weighted by the number of vessel visits in each port. *Source:* US Army Corp of Engineers, Port Clearance data.

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[15] US import values are reported on a *CIF* (Cost, Insurance, and Freight) basis, meaning they reflect the total value of goods inclusive of transport and insurance costs incurred to deliver them to the US port of entry. These components are reported separately in the US Census Bureau's import data, making it possible to observe port-level freight charges for inbound containerized trade. In contrast, US exports are reported on a *FAS* (Free Alongside Ship) basis, which excludes international freight and insurance beyond the US port of departure. Consequently, comparable export-side freight and insurance data are not available, precluding a balanced bilateral freight rate analysis.

[16] In a comparable exercise, I match quarterly trade values of containerized goods exchanged between the European Union and US subregions using both Eurostat (Comext) and US Census data. The net difference between CIF and FAS values of US exports to Europe consistently emerged as negative, while CIF less FOB values of European exports to the US produced values several magnitudes larger than reported charges. These findings mirror the asymmetries highlighted by Ardelean et al. (2022), which attributes such discrepancies to partner misreporting, differences in valuation basis, and timing mismatches in customs declarations.

5 Counterfactual

I use the empty repositioning model to consider the policy implications of OSRA22. I first outline a multi-country baseline scenario, which requires estimating bilateral loaded container flows by US trade partners. I provide a diagnostic assessment of these estimates, identify the restrictions and assumptions necessary to yield the closest fit to UNCTAD regional container traffic, and then calibrate and estimate model primitives. Upon establishing a multi-country baseline scenario, I introduce the counterfactual policy measure – an empty container outflow (ECO) quota.

5.1 Containerized Shipping Baseline

To establish a baseline multi-country scenario of US containerized trade, I require two components; (i) a set of calibrated parameters for each country's round trip with the US, which consists of the real wages, prevailing *applied* tariff rates and the price elasticity of demand for containerized goods, $\{w_j, w_i, \tau_{ij}, \tau_{ji}, \epsilon\}$, and (ii) a set of observable trade outcomes of each round trip, which reports levels of US imports, exports, loaded container inflows and loaded container outflows with each country, represented by $\{X_{ij}, X_{ji}, l_{ij}, l_{ji}\}$. For item (i), I reduce the set of unknown exogenous parameters to $\{a_{ij}, a_{ji}, c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\}$ by calibrating observable parameters based on a trade-weighted average of tariffs on manufactures, a trade-weighted average of monthly manufacturing wages, and an annual trade elasticity of demand of 12.6 estimated by Wong (2022).[17] Regarding item (ii), I do not observe loaded container traffic by country and instead estimate loaded container traffic between the US and its respective major trading partners. I use observed country-level variation in the weight and commodity type of shipped containerized goods to estimate loaded container traffic flows, as detailed in the proceeding subsection.

Given four unknowns and four equations for each round trip route, I use an exactly identified method-of-moments calibration to identify the set of unknown model primitives. Identification is obtained from two bilateral trade-value equations and two loaded-container flow equations (Equations (7) and (9)). I assume that loaded and empty handling costs are invariant by direction within a route, which yields two input-cost parameters to estimate for each round trip.[18] I set observed containerized

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[17] See Appendix Section VI for a detailed description of country-specific parameter calibrations and the limitations these requirements introduce regarding the set of eligible round trips that can be considered.

[18] In Appendix Section III, I endogenize costs to capture scale economies of larger containerships.

trade values, $\{X_{ij}, X_{ji}\}$, and estimated loaded container traffic, $\{\hat{l}_{ij}, \hat{l}_{ji}\}$, equal to average monthly 2017 levels to match the time frequency at which ϵ is estimated. I use 2017 as a stable pre-shock benchmark that predates both the China–U.S. trade war and pandemic-era disruptions.[19]

5.2 Multi-Country Container Flows

Given that I do not observe country-specific flows of loaded container units, I estimate these values using port-level variation in commodity-specific weights of containerized goods exchanged between specific US-country pairs.[20]

5.2.1 Assumptions

Container units include a set of operational characteristics defining the maximum weight each unit can carry. Ardelean et al. (2022) finds a consistent co-movement in per-unit freight rates of containerized Chilean imports across per-kilogram and per-TEU measures.[21] A positive relationship exists between the number of loaded container units used in transport and the weight of goods shipped to a given country. Individual container units also maintain cubic volume capacities. The binding constraint for a given container unit is almost always volume, rather than weight (Holmes and Singer, 2018). Differences in product dimensions alter the rate at which variation in weight contributes to the number of necessary container units used. For example, a kilogram of wooden products may utilize more of a given container's cubic volume capacity when compared to a metallic product of similar weight.

To estimate the number of TEU units utilized on a given US-trade partner round trip, I exploit monthly commodity-level variation in the weight of containerized goods, which is observed at the US port to country level. I incorporate both weight and volume considerations in the decomposition of port-level US containers,

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The cost of loaded container handling falls with route-level volume. This extension allows estimated parameters to respond more directly to variation relevant for the counterfactual analysis, but requires additional maritime data (e.g., bilateral freight rates).

[19] Importantly, the method-of-moments procedure does not match unobserved bilateral empty-container flows. The model's equipment-balance condition implies route-level empty repositioning after estimating bilateral loaded-container flows.

[20] The number of countries for which I can estimate container flows is larger than the set featured in my baseline calibration of the model. This is due to only a subset of individual countries having average monthly manufacturing wage data available from 2012 to 2021.

[21] In support of this evidence, I find that a simple log-log regression of loaded container US inflows on the weight of containerized US imports yields a 1-for-1 co-movement.

$$l_{pt}^{f} = \sum_{j=1}^{J} l_{pjt}^{f} = \sum_{j=1}^{J}\sum_{k=1}^{K} \beta^{fjk} w_{pjkt}^{f}, \ f \in \{\text{Imports}, \text{Exports}\}, \tag{14}$$

where at US port p, in year-month t, the number of loaded container units l_{pt} is the sum of containerized weights of country j for commodity k, w_{pjkt}^{f}, times respective loading factors, β_{jk}. Superscript f indicates the direction that containerized goods travel in from the US perspective. Container flows to country j can be expressed as

$$l_{US-j,t}^{f} = \sum_{p=1}^{P} l_{pt}^{f} = \sum_{p=1}^{P}\sum_{k=1}^{K} \beta^{fjk} w_{pjkt}^{f}, \tag{15}$$

where combinations of observed w_{pjkt}, and estimated $\hat{\beta}^{fjk}$ form estimated bilateral loaded flows across J routes. Using this proposed identity would imply a JK number of regressors, which is infeasible even at the HS-2 commodity level aggregation. I assume that commodity-specific loading factors do not vary across countries. For example, should workers in Mumbai fit three metric tonnes of furniture into a container unit, I assume that, on average, they use available cubic volume as efficiently as workers loading in Rotterdam. Given this assumption, my estimation can be represented as

$$l_{pt}^{f} = \sum_{k=1}^{K} \beta^{fk} \sum_{j=1}^{J} w_{pjt}^{f} + \varepsilon_{pt}^{f} \tag{16}$$

For a given commodity, volume capacity use may differ on either leg of a round trip, leading to differences in commodity-specific loading factors. Restricting loading factors β to be invariant by direction may introduce product differentiation bias within commodity-specific groups. For example, consider HS item 68 − articles of stone, plaster, and similar materials. The US may export low-quality stone masonry while higher-quality articles may originate from Japan. Should these high-quality materials be associated with relatively low volumes of kilogram weight, while low-quality US exports of stone articles are associated with high volumes of weight, this restriction would inadvertently yield a negative coefficient. As weight increases, the loading factor associated with these shipments lowers.[22]

Despite estimating loading factors across 97 HS2 commodities, I use only 72 factors of goods featured in the UNCTAD's Trade Analysis Information System (TRAINS)

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[22] To address these potential sources of bias, I have used country groupings for a given commodity that addresses potential product differentiation. Geographic and income-based country groupings for specific commodity weights have been evaluated in Online Appendix VII and generally contribute little towards improving loading factor estimates.

SITC product group of 'manufactures'. This is due to my reliance on manufacturing wage data in the calibration of the model.

5.2.2 Loading Factor Estimates

Under these assumptions, I regress Eq.(16) to generate loading factor estimates across a variety of fixed effects combinations, which control for differences in the scale of container flows at each port, local industry compositions in each port's local vicinity and biases in loading factors driven by seasonality in within-commodity variation. To assess the importance of composition differences in commodities by direction, I have estimated both direction-invariant (joint) and f-specific (separate) loading factors. These estimates are generally significant and positive in value (Figure 4).[23]

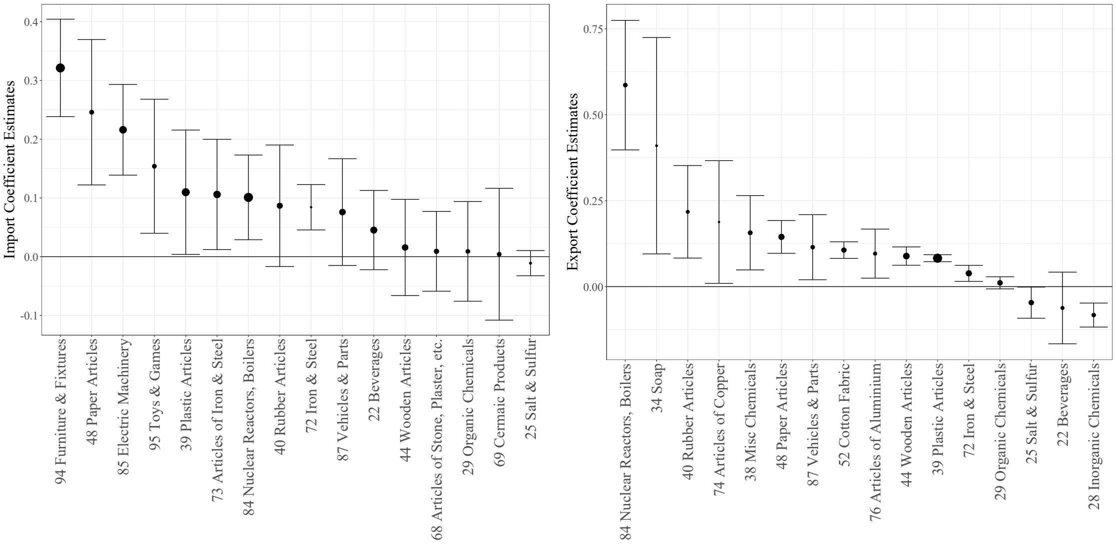

Figure 4. Loading Factor Estimates by Commodity

Clustered (port) standard-errors. Regresses monthly port-level loaded container inflows (outflows) on commodity-specific weights of containerized US imports (exports). Each coefficient can be interpreted as the average loaded container unit volume occupied by a metric ton of commodity k. Results displayed for the top 16 manufactures by value. Covers Jan-2012 to Dec-2021 and uses port & year-month fixed effects. Point sizes vary with share of trade flow.

These estimates are used to generate bilateral j-specific loading factors,

$$\hat{l}_{j-US,t} = \sum_{p=1}^{P} \hat{l}_{jpt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \hat{\beta}^{\text{Imp},k} w_{jpkt}, \quad \hat{l}_{US-j,t} = \sum_{p=1}^{P} \hat{l}_{pjt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \hat{\beta}^{\text{Exp},k} w_{pjkt},$$

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[23] A negative loading factor implies more weight of a given commodity requires fewer containers. Given 97 commodity estimates, this identification strategy is liable to false-positive findings of negative coefficients. Diagnostics in Online Appendix VII highlight that negative loading factor commodities are traded in relatively small volumes and results are not sensitive to the inclusion of negative coefficients.

where traffic is the product of commodity k's weight and a time-invariant loading factor, β^{fk}, summed across P ports and K commodities. Compared to UNCTAD loaded container flows, I find that estimated values using 'separate' loading factors are associated with lower root mean square errors compared to 'joint' estimates.

5.2.3 Container Flow Estimates

To select the preferred fixed-effects specification, I compare estimated loaded-container volumes and bilateral flow ratios to UNCTAD records of annual loaded containers exchanged on U.S.–East Asian and U.S.–European routes (UNCTAD, 2022). Although loading factors and implied country-level container flows can be constructed for many partners, I restrict the baseline sample to countries with manufacturing wage data required for model calibration over 2012–2021. I also collapse European nations to a single market entity and exclude Mexico and Canada, where land borders may weaken the link between bilateral trade flows and maritime container services.[24] Applying these product and country-sample restrictions, I recover bilateral loaded-container flows for manufactured goods across the countries shown in Figure 5.

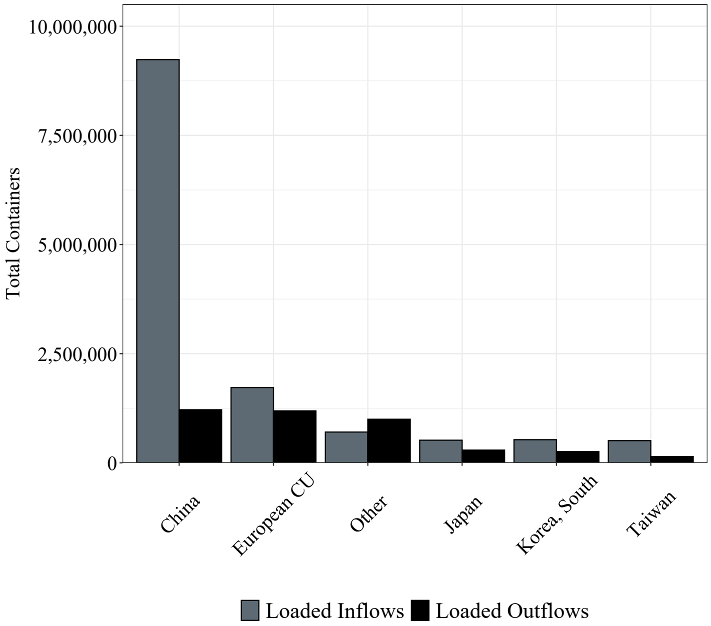

Figure 5. Estimated Container Flows by Country and Direction

Note: These estimates of manufactured goods flows across US trade partners represent 70% (50%) of containerized goods imports (exports) and 65% (43%) of loaded container inflows (outflows). 'Other' includes Argentina, Australia, Chile, Columbia, Dominican Rep., Ecuador, Malaysia, the Philippines, Singapore and Turkey.

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[24] See Online Appendix VIII for evidence of balanced container flows only at the Single Market level.

5.3 Model Fit

To assess these loading factor estimates, I construct bilateral loaded container flows across my key set of major US ports for 2012 to 2021. I aggregate these annual totals further across geographic groupings of East Asia and Europe to capture trans-Pacific or trans-Atlantic maritime commerce.

Ideally, after recovering container flows at the country-to-country level, I would prefer to assess how well the model captures these bilateral flows. To date, the most granular observations of national loaded container traffic are aggregated to broad shipping regions. Under the Ocean Shipping Reform Act of 2022 (OSRA22), the Federal Maritime Commission (FMC) is required to publish a quarterly report, accessible on its website, that includes the following details for each ocean common carrier calling at US ports; (i) total import and export tonnage and (ii) total number of loaded and empty TEUs. This information must be broken down by vessel, covering those that call at any US port, including territories and possessions. Due to transshipping, this would still likely not meet the ideal criteria that I desire, but would be a means of more closely assessing the performance of this exercise.

I contrast asymmetries in estimated loaded container flows attributed to each region against patterns documented by the UNCTAD and find a compelling fit (Figure 6). These findings suggest that at aggregated ocean-specific levels, variation in the weight of specific containerized goods can be highly predictive of the amount of associated loaded container capacity required for transportation.

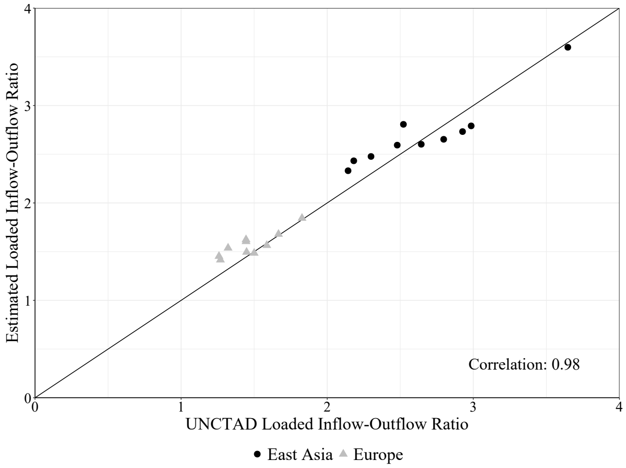

Figure 6. Model Fit – Loaded Container Ratios by Region (2012-2021)

Note: Observed levels originate from UNCTAD records on regional total loaded container flows by year and were untargeted in the estimation of individual country container flow estimates.

Upon including these estimates in a method-of-moments estimation, I find the following untargeted features and moments in the baseline model; (1) the empty repositioning share of container fleet management costs averages between 14.9–21.3%, depending on the route, which places US-related costs of empty container redistribution close to 15% share reported by Rodrigue (2020); (2) the difference in pairs of preference parameters on round trip routes attributes stronger tastes on the larger volume importing lane, with ratios of tastes being highly predictive of the skewness prevailing in trade imbalances; (3) implied freight rates are greater for legs of US round trips that feature a full set of loaded containers, which reflects empirically documented freight rate asymmetries under imbalanced trade (Hummels et al., 2009).

5.4 Counterfactual Policy Background

In this subsection, I discuss recent changes to shipping regulations through OSRA22 and the Federal Maritime Commission's subsequent amendments, which introduce a friction to empty container repositioning in favor of stimulating US exports. Motivated by this policy, I outline a setting in which the policymaker introduces a cap on empty container outflows through a per-unit wedge.

5.4.1 Pre-policy Conditions

In October 2021, vulnerabilities in US transport services became notably tangible. A resurgence of US economic activity contributed to elevated import demand and a more skewed US trade deficit. The increased asymmetry in bilateral containerized trade volumes coincided with record-high rates of empty container outflows. For example, Los Angeles reported container outflows increasing from a pre-COVID historical average of 50 percent to over 80 percent in the latter half of 2021. By 2022, three containers left the US empty for every five containers that entered the US laden with goods. Due to the higher opportunity costs of servicing loaded units and the increased volume of import traffic to the US, a greater percentage of capacity was reassigned to empty container transport. In addition, short-term frictions in adopting the necessary higher share of empty container outflows resulted in cases of transport service cancellations, which added to frustrations for agricultural US exporters. However, these frictions in negotiating for and retaining contracted vessel-allocated space contributed to a swift bipartisan response from US policymakers.

5.4.2 Ocean Shipping Reform Act 2022

In December 2021, the House of Representatives passed H.R.4996, the Ocean Shipping Reform Act of 2021.[25] This bill aimed to introduce legislation that prohibits the 'unreasonable' refusal of vessel capacity from US exports and ensure fair trade by supporting "good-paying American manufacturing jobs and agricultural exports". Senate lawmakers were explicit in further emphasizing the intent of this bill.

> *"The rulemaking under paragraph (1) shall address the unreasonableness of ocean common carriers* ***prioritizing the shipment of empty containers*** *while excluding, limiting, or otherwise reducing the shipment of full, loaded containers when such containers are readily available to be shipped and the appurtenant vessel has the weight and space capacity available to carry such containers if loaded in a safe and timely manner."*
>
> H.R.4996, the Ocean Shipping Reform Act of 2021

Upon minor changes from the US Senate, OSRA22 has since entered into public law as of June 16th 2022.[26] However, the bill did not specify how a restriction on prioritizing empties must be imposed and delegated definition to the Federal Maritime Commission (FMC). The challenge for the FMC involves defining cases of 'unreasonable refusals of vessel capacity' and devising measures to punish any violators. The FMC initially issued a Notice of Proposed Rulemaking (NPRM), which suggested that 'unreasonable' refusals must be determined on a case-by-case basis. To judge reasonability, the FMC requires ocean common carriers to provide a documented export strategy (FMC, 2022).[27] In late 2022, the FMC received comments on their proposed rulemaking from key stakeholders including the US Dairy Export Council, the International Fresh Produce Association, the Retail Industry Leaders Association, the World Shipping Council (WSC), four US senators, and seven members of

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[25] Available at https://www.congress.gov/bill/117th-congress/house-bill/4996

[26] Available at https://www.congress.gov/117/plaws/publ146/PLAW-117publ146.pdf

[27] While no report template has led to confusion among transporters, an extract of the proposal summarizes the desired contents of the report. "By way of illustration only, effective export strategies should be tailored to specific categories, such as programs, customers, markets, or commodities, and include documented policies on export business practices, including *equipment provisioning*, free time, outreach plans for contingencies and instances of imbalance in equipment availability, clearly defined and tracked performance metrics, identification of key export staff, and regular internal review of such policies. The Commission presumes that every ocean carrier operating in the U.S. market will have the ability to transport exports in addition to imports until further information is provided. In other words, an ocean carrier may not categorically exclude US exports from a backhaul trip without showing how this action is reasonable."

US congress.[28] Senators explicitly reiterated the intent of OSRA22, stating that "the need to require such a clarification arose specifically from reports of ocean carriers refusing certain export cargo ... even when vessel space was readily available, often opting to carry empty containers instead." Members of Congress added that "ocean carriers refusing to accommodate American exports is an unreasonable business practice and, following passage of the Ocean Shipping Reform Act of 2022, also is now illegal." The WSC, an association that represents 90% of transport operators, clarified the operational realities that contribute to empty repositioning (WSC, 2022).

> *"...the proposed regulatory language does not address in any way the basic reality that imbalanced trades (as reflected in the preamble) require the repositioning of equipment, which adds dimension to planning and operating vessel networks. It defies the reality of ocean transportation to ignore these complexities and to treat the export and import legs of a trade as unrelated."*

As of September 2024, following further rulemaking, if the refusal occurs after an agreement has been reached and a booking confirmation issued, it pertains to 46 U.S.C. § 41104(a)(3), which covers unreasonable refusals of cargo space accommodations while contracted to do so (i.e. cancellations and delayed shipping). If a refusal happens during negotiations, it falls under 46 U.S.C. § 41104(a)(10), which addresses unreasonable refusals to deal or negotiate. As of March 2025, requirements for ocean common carriers to file a documented export policy with the FMC are in effect.[29] This latter amendment on refusals to negotiate cargo space with US exporters, in favor of repositioning transport equipment, represents a long-term friction towards outbound empty repositioning that motivates my counterfactual exercise.

There is limited guidance on how a newly required export strategy by ocean carriers would be used to evaluate individual cases of alleged unreasonable refusals to deal or negotiate. The vague standard of what constitutes an "unreasonable" refusal to provide vessel space, including a "de facto, absolute, or systematic exclusion of exports in providing cargo space accommodations," creates legal uncertainty and can be interpreted as an intensive-margin constraint on empty-container repositioning. To understand the implications of such frictions, I consider a counterfactual exercise that captures the policy intent of limiting empty repositioning in favor of greater capacity allocation toward U.S. exporters.

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[28] The full set of public commentaries is available at https://www2.fmc.gov/readingroom/proceeding/22-24/. Last accessed as of 02/21/2025.

[29] Details are available at https://www.fmc.gov/articles/deadline-announced-for-required-filing-of-annual-export-strategies-at-fmc/. Last accessed as of 02/21/2025.

I introduce a simple per-unit wedge on empty-container outflows, where the wedge, γ, is calibrated to target a capped share of empties as a percentage of total container outflows. I assume U.S. policymakers are content with returning to the prior empty-repositioning status quo and use a moderate target, the historical U.S. empty share of 40% of container outflows. The counterfactual should not be interpreted as a literal simulation of every statutory provision in OSRA22. Instead, it isolates the economic mechanism emphasized by the policy debate. Restrictions on carriers' ability to allocate scarce outbound capacity to empty repositioning rather than loaded export cargo.

5.5 Main Results

As shown in Table 5, a moderate empty container outflow (ECO) quota stimulates US exports. Exporters take advantage of lower freight rates on round-trip services to net exporter countries, shifting from empty to loaded container flows. The US containerized trade deficit, measured by the import-export ratio, falls by 37.3%. However, focusing solely on the outbound leg misses broader round-trip effects that also matter for policymakers.

Table. 5. Disaggregated Counterfactual Outcomes

U.S. Measures	Imports	Exports	Imp. Price	Exp. Price	Value	Vol.	Capacity
Δ%	-17.1	30.0	2.3	-5.7	-8.2	-4.3	-18.5

Note: These results reflect percentage changes from their respective 2017 baseline scenarios of the partial equilibrium model and are based on estimates of loaded container flows & observed levels of associated trade in containerized manufactured goods.

Accounting for bilateral round-trip effects, U.S. real imports decline by 17.1%.[30] This result stems from higher costs of returning empty containers, which are fully passed on to import prices under perfect competition. Consequently, the price of imports rises by 2.2%, while export prices fall by 5.6%. Total TEU capacity on roundtrip services drops by 18.4%, reflecting reduced container redistribution. The empty container share of total US outbound flows declines by 37.4%. The ECO quota directly constrains the extent to which trade imbalances can persist internationally. Unlike policies that implicitly burden manufacturing sectors (Dekle et al., 2007), this intervention shifts the adjustment margin to the transportation system.

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[30] An equivalent import reduction requires a 34 percentage point increase in effective import tariffs, which reduces empty container outflows by only half as much as the ECO quota.

While adjustments in individual flow measures and the trade balance are of interest, understanding changes to the scale of overall trade activity is of the greatest importance in this setting. Should overall trade activity decline, so too would the associated gains from trade. In the case of the multi-country setup, a moderate ECO quota contributes to an 8.2% (4.3%) decline in the value (volume) of containerized trade, which suggests a degradation in the gains to trade the US and its trade partners would have otherwise been able to accrue.

Across the subset of net exporters that engage in containerized trade with the US, pre-existing reliance on empty container repositioning acts as a strong predictor of this policy's effectiveness. Measuring the degree of reliance as US outflows of empties to country i as a percentage of total US container outflows to country i, I find that countries with greater shares of empty inflows yielded the highest declines in imports. As highlighted in Figure 7, East Asian trade partners maintained the highest empty container shares in the predefined baseline scenario. Upon the introduction of a per-unit wedge on empty repositioning, these particularly asymmetric trade routes faced the greatest contractionary pressure.

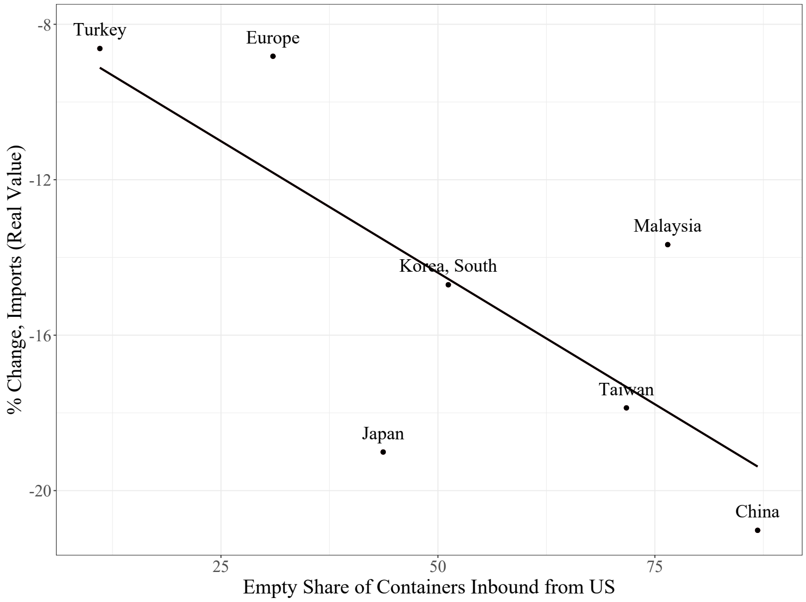

Figure 7. US Import Value by Net Exporter (2017)

Note: The real value of imports is used, deflated by US CPI for urban areas, less food and energy. The empty share represents $100 * \frac{\text{US-Country Empty Outflows}}{\text{Total US-Country Outflows}}$, and reflects pre-policy shares of total container outflows.

The sizable loss in transport equipment accessibility and the acuteness of this decline on routes with relatively high dependencies on empty repositioning leads to reconfigured shares of the US import market (Figure 8). Some net exporter countries gain market share due to being harmed to a lesser degree. China, which receives four empty returns for every five loaded containers shipped to the US, suffers a two percentage point loss in its share of US imports. Given Europe's relatively weaker dependency, although imports do decline, the overall decline in total US containerized imports falls by a greater margin. This results in the European Customs Area gaining a larger market share, despite being negatively affected by the policy.

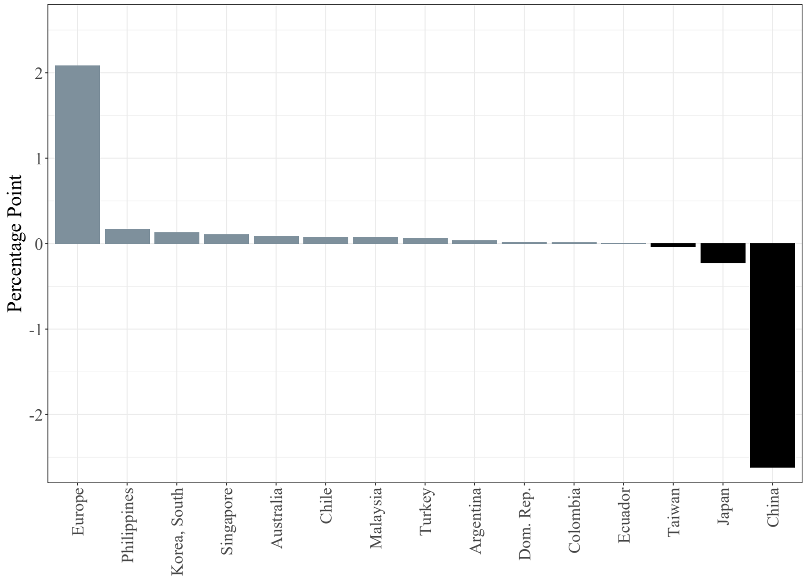

Figure 8. Change in Trade Partner Shares of US imports (2017)

Note: Real values of imports are deflated using US CPI for urban areas, less food and energy.

Before valuing empty repositioning directly, I consider the sensitivity of these results to the mapping between observed manufacturing wages and the non-transport cost component of a representative containerized shipment. The baseline calibration uses monthly manufacturing wages as the observable production-cost shifter. However, containerized shipment values also reflect intermediate inputs, capital intensity, markups, and differences in product composition. In Appendix Section IX, I augment the baseline model with route-direction production-cost conversion factors, B_{ij} and B_{ji}, which scale observed wages in the two bilateral price equations. I discipline these additional parameters using OECD bilateral transport and insurance margins, targeting the model-implied transport-cost shares $T_{ij}l_{ij}/X_{ij}$ and $T_{ji}l_{ji}/X_{ji}$. Given that these margins cover all transport modes rather than maritime container services alone, I interpret the exercise as a robustness check rather than a replacement calibration. The central quantitative conclusion is preserved. The ECO quota continues to reduce total trade value and shipping capacity by magnitudes close to the baseline, although the export expansion is more conservative.

5.5.1 Valuing Empty Repositioning

Operators lower outbound transport prices to incentivize greater container utilization for US exports, while limiting inbound volume to avoid costly repositioning requirements. In this counterfactual scenario, no empty containers are transported.

The economic contribution of empty container repositioning to multilateral trade outcomes can be examined by making this logistical practice financially infeasible. By elevating the per-unit wedge on empty container outflows, γ_{ji}, the cost of transporting empty container units rises. As servicing asymmetries on US shipping lanes becomes more costly, transport operators respond by adjusting freight rates. To reduce the degree of volume imbalance, high-volume US import legs experience rising transport service prices, while lower-volume export legs see freight prices fall. Operators lower outbound transport prices to incentivize greater container utilization for US exports, while raising inbound prices to avoid costly repositioning obligations. In this counterfactual scenario, no empty containers are transported.

Table 6 reports the partial equilibrium effects of a complete ban on empty container flows. Relative to the 2017 baseline, total US containerized trade value declines by 11.5%, driven by a 28.8% contraction in imports. This effect is partially offset by a 62.7% increase in exports, driven by the decline in outbound freight prices.[31] Vessel capacity on US trade routes falls by 32.2%, which accompanies a 117.3 billion reduction in trade value based on 2017 levels of $1.02 trillion. When accounting for the 5.1% increase in US import prices and the disruptive effects of constrained access to intermediate goods, the broader macroeconomic consequences of this logistical restriction would likely be larger.

Table. 6. Explicit Empty Container Ban

U.S. Measures	Imports	Exports	Imp. Price	Exp. Price	Value	Vol.	Capacity
Δ%	-28.8	62.7	5.1	-24.9	-11.5	-0.57	-32.2

Note: These results reflect percentage changes from their respective 2017 baseline scenarios of the partial equilibrium model and are based on estimates of loaded container flows & observed levels of associated trade in containerized manufactured goods.

This evidence supports recent initiatives across European ports that aim to reduce container handling costs. The European Union has provided direct financial support for the development and commercialization of foldable container technol-

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[31] From the representative US exporter's perspective, this represents a 25% reduction in the price of their products.

ogy, primarily through the Horizon 2020 innovation program. Such equipment offers cost savings through multiple channels, including improved storage density and reduced crane time during vessel unloading (Konings, 2005; Moon et al., 2013). If such innovations successfully reduce the cost of servicing asymmetries in trade volumes, this paper suggests that container traffic, and associated gains from trade, should increase. However, several caveats limit the full realization of foldable container benefits. These containers are more expensive to manufacture, require port-side folding and unfolding labor, and may be less durable than standard models. Limited adoption also constrains scale economies, reducing the cost-effectiveness of the technology. While standard containers typically last 13–15 years, the lifespan of foldable units may be shorter, further increasing the burden of upfront capital investment. Should these challenges be met, adopting countries should anticipate higher effective shipping supply, lower transport prices and greater access to international markets.

6 Conclusion

This paper provides a micro-founded quantitative approach to understanding how container repositioning influences trade outcomes. By internalizing the cost of repositioning container units faced by transport operators, I demonstrate that variation in empty handling costs affects trade outcomes on both legs of a given round trip. As these costs decline, the global shipping fleet becomes more capable of servicing large trade asymmetries, enabling greater bilateral trade volumes.

Using novel container traffic data, representing 80% of gross US container traffic, I show that despite a persistent US trade deficit, the national exchange of container units with the rest of the world remains balanced. I also document that opposite-leg trade outcomes are a key driver of the extent to which US empty container repositioning occurs. Additionally, I find that US ports exhibit specialization as either net inflow or net outflow hubs for containers, even as national exchanges remain balanced throughout the sample period.

By physically modeling container units in the joint profit maximization problem of transport operators, I address a longstanding challenge in modeling imbalanced round trip trade. The lower-volume leg of perfectly competitive transport models, with perfect foresight across agents, yields a freight rate of zero. This challenge is not unique to maritime commerce and is applicable across multiple modes of transport. Furthermore, in a model extension I show that scale economies from larger containerships amplify comparative statics of this partial equilibrium framework, while the introduction of indirect shipping routes dampens them.

I also quantitatively assess how interfering with this logistical practice affects trade flows. Whereas trade policy has traditionally focused on demand-side instruments such as tariffs and quotas, relatively little is known about the effects of regulating transport inputs. The counterfactual analysis of this paper is motivated by the Ocean Shipping Reform Act of 2022 (OSRA22), which targets carrier behavior that prioritizes empty repositioning over available loaded U.S. export cargo. I model this as a stylized capacity-allocation constraint that limits the empty share of U.S. outbound container movements. To quote the World Shipping Council's response to OSRA22: "It defies the reality of ocean transportation to ignore these complexities and to treat the export and import legs of a trade as unrelated." My findings suggest that intervention in container repositioning can produce unintended and adverse consequences. In particular, vessel capacity serving the US may decline due to the added cost of servicing trade imbalances. While exports rise slightly within affected trade lanes, this is outweighed by a decline in imports, or approximately \$133 billion (0.68% of GDP), overall trade value falling by 8.2%, and increased inflationary pressure on US consumers. In assessing the full value of empty container repositioning, I estimate a 12% decline in the US containerized trade and a 32% reduction in available shipping capacity. Regulation of liner shipping should therefore consider the joint effects on both legs of round-trip traffic, rather than focusing narrowly on exports.

While this paper sets a foundation that documents empty repositioning and demonstrates that it is not the result of a market failure, further research is needed on the multi-port transport networks over which containers flow. As maritime data improves, particularly through advances in container tracking, future work will be able to trace container paths more precisely. This will aid in identifying the factors that drive port specialization and help detect potential bottlenecks in the global transportation network.

Online Appendix

I. General Equilibrium with Homogeneous Input Prices

The assumption of common input prices across loaded and empty containers is a generalizing restriction that yields zero freight rates for transport services originating from net importer countries. Consider equation (3):

$$\max_{l_{ij},l_{ji},e_{ij},e_{ji}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - c_{ij}l_{ij} - c_{ji}l_{ji} - r_{ij}e_{ij} + r_{ji}e_{ji} \;\; \text{s.t. } \; l_{ij} + e_{ij} = l_{ji} + e_{ji}$$

I adjust this specification to a more general form which sets all container input prices equal to a route-specific cost term $\{c_{ij}, c_{ji}, r_{ij}, r_{ji}\} = c_{\overset{\leftrightarrow}{ij}}$. Consider Case II in which a trade imbalance exists between countries i and j such that $l_{ij} = l_{ji} + e_{ji}$ and $e_{ij} = 0$. Under these circumstances, imbalanced trade and balanced container flows imply a zero freight rate on route ji.

$$\begin{aligned}
\max_{l_{ij},l_{ji},e_{ij},e_{ji}} \pi_{\overset{\leftrightarrow}{ij}} =& T_{ij}l_{ij} + T_{ji}l_{ji} - c_{\overset{\leftrightarrow}{ij}}l_{ij} - c_{\overset{\leftrightarrow}{ij}}l_{ji} - c_{\overset{\leftrightarrow}{ij}}(e_{ji}) \quad \text{s.t.} \quad l_{ij} = l_{ji} + e_{ji} \\
=& T_{ij}l_{ij} + T_{ji}l_{ji} - c_{\overset{\leftrightarrow}{ij}}(l_{ij} + l_{ji} + l_{ij} - l_{ji}) \\
\text{FOC: } \frac{\partial \pi_{\overset{\leftrightarrow}{ij}}}{\partial l_{ij}} =& 0 \implies T_{ij} = 2c_{ij}, \quad \frac{\partial \pi_{\overset{\leftrightarrow}{ij}}}{\partial l_{ji}} = 0 \implies T_{ji} = 0
\end{aligned}$$

Similarly to Behrens and Picard (2011), I find that both bilateral freight rates of a given round trip route are non-zero only when shipments of loaded containers are balanced.[32] Differences in handling costs between empty and loaded containers, reflected through heterogeneous input prices within route, yield positive freight rates for both sides of an imbalanced round trip trade on $\overset{\leftrightarrow}{ij}$.

II. Balanced Trade Scenario

The perfectly competitive transport operator will yield prices where the marginal benefit of an additional loaded container transport is equal to the marginal cost. Using the implied l_{ji} from equation (4), and setting these quantities equal, we arrive at a case of two equations and two unknowns for $\{l_{ij}, T_{ij}\}$. Setting these equations

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[32] In practice, incoming loaded containers being converted into an input for outgoing transport services involve more time, weight, and cleaning relative to incoming empty containers. This suggests higher marginal costs of revenue-generating loaded container inputs relative to using inbound empties to service outbound transport services.

equal allows for freight rates to be solved.

$$\begin{aligned}\left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}(w_i\tau_{ij}+T_{ij})^{-\epsilon} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\right)^{-\epsilon}\left(w_j\tau_{ji}c_{\underset{ij}{\leftrightarrow}}+c_{\underset{ij}{\leftrightarrow}}-T_{ij}\right)^{-\epsilon} \\ (a_{ij}+a_{ji})\,T_{ij} &= a_{ij}\left(2c_{\underset{ij}{\leftrightarrow}}\right)-a_{ji}\,(w_i\tau_{ij})+a_{ij}\,(w_j\tau_{ji}) \\ T^*_{ij} &= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\underset{ij}{\leftrightarrow}})-\frac{1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij})+\frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \qquad (17)\end{aligned}$$

With freight rates expressed in terms of exogenous variables, solving for p^*_{ij} is relatively straightforward and simplifies solving for l^*_{ij}.

$$\begin{aligned}p^*_{ij} &= w_i\tau_{ij}+T^*_{ij} \\ &= w_i\tau_{ij}+\frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\underset{ij}{\leftrightarrow}})-\frac{1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij})+\frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \\ &= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\underset{ij}{\leftrightarrow}})+\frac{1+\frac{a_{ij}}{a_{ji}}-1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij})+\frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \\ p^*_{ij} &= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\underset{ij}{\leftrightarrow}}+w_i\tau_{ij}+w_j\tau_{ji}\right) \qquad (18)\end{aligned}$$

To solve for l^*_{ij}, plug T^*_{ij} into equation (4).

$$l^*_{ij} = \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(\frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\underset{ij}{\leftrightarrow}}+w_i\tau_{ij}+w_j\tau_{ji}\right)\right)^{-\epsilon} \qquad (19)$$

The equilibrium value of trade is simply price times quantity:

$$X^*_{ij} = \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(\frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\underset{ij}{\leftrightarrow}}+w_i\tau_{ij}+w_j\tau_{ji}\right)\right)^{1-\epsilon} \qquad (20)$$

III. Model Extensions

The baseline model abstracts from several mechanisms emphasized in recent trade and transport research—such as scale economies, input-output linkages, overcapacity in shipping, network spillovers (e.g., *ij* tariffs affecting *ji* trade), and cost minimization across interlinked trade routes. While incorporating all such features lies beyond the scope of this paper, I extend the framework along two dimensions: (1) scale economies in containerized transport, and (2) indirect routing through third countries. These additions serve two purposes. First, they validate the robustness of the core comparative statics. Second, they provide insights for future empirical implementation, particularly where detailed maritime data become available.

Scale Economies

The original model assumed constant per-unit container handling costs, as in Behrens and Picard (2011). However, empirical evidence from Ganapati et al. (2024) and others documents substantial economies of scale in ocean freight. The transport costs of larger containerized volumes of goods are typically lower due to scale economies offered by supersized vessels. This aspect of maritime transport has fueled a steady rise in average containership sizes over the last five decades. To reflect this, I allow marginal handling costs to decline in loaded volume, assuming a frictionless reallocation of high-capacity vessels to routes with greater throughput.

$$\begin{aligned} \max_{\{l_{ij}, l_{ji}, e_{ij}, e_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} =& T_{ij} l_{ij} + T_{ji} l_{ji} - c_{ij} l_{ij} - c_{ji} l_{ji} - r_{ij} e_{ij} - r_{ji} e_{ji} \\ &\text{s.t. } l_{ij} + e_{ij} = l_{ji} + e_{ji}, \\ &\text{where } c_{ij} = \mu_{ij} - \kappa_{ij} l_{ij}^{\phi} \text{ and } c_{ji} = \mu_{ji} - \kappa_{ji} l_{ji}^{\phi} \end{aligned}$$

Supposing weakly imbalanced trade, such that country j is a weak net importer, this allows for empty repositioning activity where $l_{ij} \geq l_{ji}$.

$$\begin{aligned} \max_{\{l_{ij}, l_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} =& T_{ij} l_{ij} + T_{ji} l_{ji} - \left(\mu_{ij} - \kappa_{ij} l_{ij}^{\phi}\right) l_{ij} - \left(\mu_{ji} - \kappa_{ji} l_{ji}^{\phi}\right) l_{ji} \\ &- r_{ji} \left(l_{ij} - l_{ji}\right), \quad \text{where } \phi \in \{0, 1\} \end{aligned}$$

Solving for the first-order conditions with respect to l_{ij} and l_{ji}, and combining these expressions with Armington consumer demand yields four equations and four unknowns. However, each of these expressions outlines a non-linear relationship between freight rates and loaded container flows.

$$\begin{aligned} T_{ij} =& \mu_{ij} - \phi \kappa_{ij} l_{ij}^{\phi} + r_{ji} \\ T_{ji} =& \mu_{ji} - \phi \kappa_{ji} l_{ji}^{\phi} - r_{ji} \\ l_{ij} =& \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}}\right)^{-\epsilon} \left(w_i \tau_{ij} + T_{ij}\right)^{-\epsilon} \\ l_{ji} =& \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ji}}\right)^{-\epsilon} \left(w_j \tau_{ji} + T_{ji}\right)^{-\epsilon} \end{aligned}$$

Given these non-linearities, I take a numerical rather than analytical approach towards examining the implied comparative statics of an empty container repositioning model with scale economies in loaded container flows. Upon simulating the model depicted above with a given set of exogenous variables, I compare the outcomes across four scenarios. These scenarios involve active and inactive scale economies, alongside lower and higher empty repositioning costs, allowing me to compare how each outcome responds to elevated empty handling costs with and without scale economies.

In all cases, higher empty costs reduce total loaded flows and increase import freight rates, consistent with the base model. However, the presence of scale economies amplifies the magnitude of these comparative statics. The presence of scale economies magnifies price and volume responses to elevated repositioning costs. For instance, a 1.7% drop in US imports under scale economies exceeds the 1.5% drop without them. The scale of the empty repositioning problem also contracts more rapidly when scale economies are present.

Importantly, the direction of changes is preserved regardless of the cost structure, suggesting robustness of the baseline model to nonlinear extensions. However, incorporating scale economies may be critical for accurately quantifying policy effects.

Indirect Transport Networks

The baseline model treats bilateral trade as operating on balanced, direct shipping loops. Yet real-world container traffic often flows via multi-stop networks, where equipment balancing occurs over entire vessel loops. Third-country routing introduces new substitution margins. Trade between i and j may be rerouted through k if doing so minimizes costs.

I extend the model to a three-country setting, which can be generalized to more complex cases of endogenous transport route selection. A transport operator chooses flows over ikj and jki segments under fixed vessel capacity. Figure 9 illustrates two configurations: direct bilateral links between all countries (panel a), and indirect routing via k (panel b). I continue to assume that j embodies the conditions of the US and operates as a weak net importer, but I relax this depicition in Case III of this model extension.[33] I assume a transport operator servicing bundles of country-specific goods flows devote a fixed vessel capacity across route ikj, if this routing minimizes total shipping costs relative to three bilateral roundtrips.

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[33] The US maintains a net importer relationship with the majority of its trade partners. Despite recent data suggesting that 60% of containers leave the US are empty, only 3% of containers enter the US empty.

(a) All country pairs are directly connected. **(b)** Indirect connection via k.

Figure 9. Two transport network configurations among i, j, and k. Panel (a) assumes direct connectivity between all pairs; panel (b) routes all flows indirectly via k.

The general profit function becomes:

$$\begin{aligned}\max_{\lambda} \pi = {} & T_{ik}l_{ik} + T_{kj}l_{kj} + T_{ij}l_{ij} + T_{ji}l_{ji} + T_{jk}l_{jk} + T_{ki}l_{ki} \\ & - c_{ik}(l_{ik} + l_{ij}) - c_{kj}(l_{kj} + l_{ij}) - c_{jk}(l_{jk} + l_{ji}) - c_{ki}(l_{ki} + l_{ji}) \\ & - r_{ik}e_{ik} - r_{ki}e_{ki} - r_{jk}e_{jk} - r_{kj}e_{kj}, \\ \text{s.t.} \quad & l_{ik} + l_{ij} + e_{ik} = l_{ki} + l_{ji} + e_{ki}, \\ & l_{kj} + l_{ij} + e_{kj} = l_{jk} + l_{ji} + e_{jk},\end{aligned}$$

where $\lambda = (l_{ik}, l_{kj}, l_{ij}, l_{ki}, l_{jk}, l_{ji}, e_{ik}, e_{ki}, e_{kj}, e_{jk})$. While loaded container units are comprised of every pair of prospective trade partners' goods, empty containers are only capable of featuring on ik, kj, jk, ki legs of transit. The direction in which empty containers are repositioned depends on whether specific bilateral shipping lanes on this multi-country route feature net exporter (NE) or net importer (NI) relationships. I next breakdown how this specification varies across all relevant permuations of these relationships; 'NE-NE', 'NI-NE', and 'NE-NI'.

Case I, NE-NE: Considering the ijk combination, more loaded container units travel from i to k and from k to j than their respective backhaul legs of ki and jk. The set of capacity constraints can be updated and incorporated into the profit maximization to simplify solving the model for freight rates. Given that no empty containers travel on the high-volume lanes of trade – $(e_{ik}, e_{jk}) = 0$. The capacity constraint equations can be expressed as $e_{ki} = l_{ik} + l_{ij} - l_{ki} - l_{ji}$ and $e_{jk} = l_{kj} + l_{ij} - l_{jk} - l_{ji}$. Upon incorporating these terms into the profit maximization problem, it simplifies to;

$$\begin{aligned}\max_{\lambda'} \pi = {} & T_{ik}l_{ik} + T_{kj}l_{kj} + T_{ij}l_{ij} + T_{ji}l_{ji} + T_{jk}l_{jk} + T_{ki}l_{ki} \\ & - c_{ik}(l_{ik} + l_{ij}) - c_{kj}(l_{kj} + l_{ij}) - c_{jk}(l_{jk} + l_{ji}) - c_{ki}(l_{ki} + l_{ji}) \\ & - r_{ki}\left(l_{ik} + l_{ij} - l_{ki} - l_{ji}\right) - r_{jk}\left(l_{kj} + l_{ij} - l_{jk} - l_{ji}\right),\end{aligned}$$

Taking the first order conditions of the model with respect to $\lambda' = (l_{ik}, l_{kj}, l_{ij}, l_{ki}, l_{jk}, l_{ji})$;

$$\begin{aligned}
\partial\pi/\partial l_{ik}:\ T_{ik} &= c_{ik} + r_{ki}, & \partial\pi/\partial l_{ki}:\ T_{ki} &= c_{ki} - r_{ki}\\
\partial\pi/\partial l_{kj}:\ T_{kj} &= c_{kj} + r_{jk}, & \partial\pi/\partial l_{jk}:\ T_{jk} &= c_{jk} - r_{jk}\\
\partial\pi/\partial l_{ij}:\ T_{ij} &= c_{ik} + c_{kj} + r_{ki} + r_{jk}, & \partial\pi/\partial l_{ji}:\ T_{ji} &= c_{jk} + c_{ki} - r_{ki} - r_{jk}
\end{aligned}$$

As in the main body of this paper, I attribute the US policymaker perspective to j. An added empty container flow friction, , is represented through r_{jk} rising. Rising empty container outflow costs from j, akin to the counterfactual exercise and OSRA22, increase inbound freight rates and reduce outbound rates, just as in the baseline model. Prices have adjusted multilaterally to internalize higher repositioning burdens and narrow the extent to which trade asymmetries are serviced on this indirect transport route.

Case II, NI-NE: In this case i acts as a net importer of goods on the $ik - ki$ leg of trade. I set the status of leg $jk - kj$ as identical to Case I.

Given that no empty containers travel on the high-volume lanes of trade $-$ $(e_{ki}, e_{jk}) = 0$. The capacity constraint equations can be expressed as $e_{ik} = l_{ki} + l_{ji} - l_{ik} - l_{ij}$ and $e_{jk} = l_{kj} + l_{ij} - l_{jk} - l_{ji}$. Upon incorporating these terms into the profit maximization problem, it simplifies to;

$$\begin{aligned}
\max_{\lambda'} \pi = {} & T_{ik}l_{ik} + T_{kj}l_{kj} + T_{ij}l_{ij} + T_{ji}l_{ji} + T_{jk}l_{jk} + T_{ki}l_{ki}\\
& - c_{ik}(l_{ik} + l_{ij}) - c_{kj}(l_{kj} + l_{ij}) - c_{jk}(l_{jk} + l_{ji}) - c_{ki}(l_{ki} + l_{ji})\\
& - r_{ik}\left(l_{ki} + l_{ji} - l_{ik} - l_{ij}\right) - r_{jk}\left(l_{kj} + l_{ij} - l_{jk} - l_{ji}\right),
\end{aligned}$$

Taking the first order conditions of the model with respect to $\lambda' = (l_{ik}, l_{kj}, l_{ij}, l_{ki}, l_{jk}, l_{ji})$;

$$\begin{aligned}
\partial\pi/\partial l_{ik}:\ T_{ik} &= c_{ik} + r_{ik}, & \partial\pi/\partial l_{ki}:\ T_{ki} &= c_{ki} + r_{ik}\\
\partial\pi/\partial l_{kj}:\ T_{kj} &= c_{kj} + r_{jk}, & \partial\pi/\partial l_{jk}:\ T_{jk} &= c_{jk} - r_{jk}\\
\partial\pi/\partial l_{ij}:\ T_{ij} &= c_{ik} + c_{kj} - r_{ik} + r_{jk}, & \partial\pi/\partial l_{ji}:\ T_{ji} &= c_{jk} + c_{ki} + r_{ik} - r_{jk}
\end{aligned}$$

Upon r_{jk} rising, the directional effects of the model mirror those in Case I. Prices are simultaneously adjusted to narrow the extent to which trade asymmetries are serviced on this indirect transport route.

Case III, NE-NI: In this last case, I consider a scenario where high-volume transit occurs on legs ik and jk. This implies that empty container repositioning occurs on the opposing legs of trade, ki and kj, where $e_{kj} = l_{jk} + l_{ji} - l_{kj} - l_{ij}$ and $e_{ki} = l_{ik} + l_{ij} - l_{ki} - l_{ji}$. Embedding these constraints into the profit maximization problem leads to the following specification;

$$\begin{aligned}\max_{\lambda'} \pi = & T_{ik}l_{ik} + T_{kj}l_{kj} + T_{ij}l_{ij} + T_{ji}l_{ji} + T_{jk}l_{jk} + T_{ki}l_{ki} \\ & - c_{ik}(l_{ik} + l_{ij}) - c_{kj}(l_{kj} + l_{ij}) - c_{jk}(l_{jk} + l_{ji}) - c_{ki}(l_{ki} + l_{ji}) \\ & - r_{ki}\left(l_{ik} + l_{ij} - l_{ki} - l_{ji}\right) - r_{kj}\left(l_{jk} + l_{ji} - l_{kj} - l_{ij}\right),\end{aligned}$$

In this case, trade outcomes are not sensitive to policy changes that affect the cost of shipping empties from j. As long as loaded container volume from k to j outscales its opposite leg, there is a capacity on this route to absorb volume from alternative routes. For example, consider a scenario where the transport operator initially conducts transport services such that container flows reflect panel A of Figure 9 due to this process minimizing costs. Suppose the government of j introduces an empty container outflow tax. Assuming that k acts as a net importer of container units from j, as detailed above, the bilateral container traffic between i and j could be trafficked indirectly through k. Due to government intervention, this route is the new cost minimizing option. Shifting traffic towards it would reducing the overall burden of empty container repositioning, potentially eliminating it completely if e_{kj} is large enough to absorb the relatively larger volume of containerized goods travelling from i to j. The comparative static $\partial T_{ij}/\partial r_{ji}$ equals zero if there is a sufficiently large amount of 'net importer' trade partners maintained by j through which convenient indirect transport networks can be formed that absorb all of the volume of the origin direct route, eliminating empty traffic.

In the case of the US, 'net importer' relationships are sparse and associated with relatively trade partners. This is reflected by the fact that while over 60% of containers leave the US empty, only 3% of container return empty. Examining individual origin-destination pairs of containerized goods shipping, and converting commodity-specific weights of goods flows into loaded container volumes, only a small fraction of US trade partners act as net importers of container units originating from the US, irrespective of routing (Figure 5). This implies that while strategic behaviour of indirect routes to 'net-out' empty container outflows is possible to mitigate the impact of elevated empty outflow costs, there is not a sufficiently large enough pool of alternative routes nor sufficient capacity to pursue this option at a meaningful scale in the case of the US.

For countries with more balanced or outbound-heavy trade patterns, this depiction of indirect shipping networks could be important towards accurately capturing the dampened effect of empty container outflow frictions on containerized trade outcomes.

IV. Container Traffic Sample

This appendix provides additional information on the port-level container traffic data used in the descriptive analysis. The underlying port records report monthly loaded and empty container flows by direction. To preserve the value of the port-level data collection, I report national and grouped aggregates rather than port-month observations. These summaries document the sample coverage, the scale of loaded and empty flows, and the historical benchmark used to motivate the counterfactual empty-container outflow target.

Table. A.1. Sample Representation - US Total Container Throughput

Year	Number of Ports	Sample TEU	National TEU	% of National
2003	8	21,150,609	32,689,484	64.70
2004	8	23,357,414	34,901,628	66.92
2005	8	25,826,230	38,497,839	67.08
2006	8	27,661,831	40,896,742	67.64
2007	8	27,797,684	44,839,390	61.99
2008	9	26,652,498	42,411,770	62.84
2009	10	23,169,814	37,353,575	62.03
2010	10	27,122,000	40,266,186	67.36
2011	11	29,181,883	40,813,311	71.50
2012	12	35,350,843	41,880,574	84.41
2013	12	35,937,976	42,842,910	83.88
2014	12	37,548,916	44,635,035	84.12
2015	13	40,501,360	46,496,985	87.11
2016	13	41,021,434	46,940,227	87.39
2017	13	44,209,298	50,202,917	88.06
2018	13	46,619,407	53,045,976	87.88
2019	13	47,064,791	54,259,399	86.74
2020	13	46,555,563	53,035,170	87.78
2021	13	53,748,362	60,771,719	88.44
2022	12	52,711,676	61,033,758	86.36
2023	12	46,188,880	54,282,705	85.09
2024	12	51,843,726	-	-

Source: National thruflows use 'Container port throughput, annual' from UNCTAD. Last updated March 24 2025.

Table A.1 reports the coverage of the assembled port sample relative to national container throughput. Column two reports the number of ports contributing container traffic records in a given year. Column three reports total loaded and empty container units handled by the reporting ports. Column four displays national loaded and empty container throughput, and column five reports the sample's share of national throughput. National measures are sourced from UNCTAD and report total containers handled, expressed in twenty-foot equivalent units (TEUs). A TEU represents the volume of a standard 20-foot intermodal container used for loading, unloading, repositioning, and transshipment.

Table. A.2. National Monthly Container Flow Summary Statistics

Variable	Unit	Mean	SD	P25	Median	P75	Min	Max
Absolute total-flow imbalance	%	3.20	2.38	1.24	2.79	4.72	0.01	10.81
Inbound empty share	%	6.81	2.40	4.83	6.15	8.65	3.05	13.87
Empty inflows	million TEU	0.12	0.03	0.10	0.11	0.14	0.07	0.19
Empty outflows less empty inflows	million TEU	0.75	0.31	0.52	0.72	0.97	0.16	1.36
Outbound empty share	%	46.50	9.12	39.64	46.37	54.07	26.35	62.67
Empty outflows	million TEU	0.87	0.29	0.65	0.84	1.07	0.33	1.45
Loaded inflows	million TEU	1.73	0.30	1.49	1.71	1.95	1.09	2.37
Loaded outflows	million TEU	0.95	0.07	0.91	0.95	0.99	0.79	1.13
Net total inflow	million TEU	0.03	0.07	0.00	0.04	0.08	-0.18	0.18
Total inflows	million TEU	1.85	0.29	1.63	1.83	2.06	1.26	2.46
Total outflows	million TEU	1.82	0.27	1.60	1.81	2.01	1.26	2.42

Note: The table reports summary statistics across national monthly aggregates constructed from the balanced 2012–2024 port panel. TEU variables are reported in millions. Shares are reported in percentage points. The underlying port-month observations are not reported.

Table. A.3. Annual National Loaded and Empty Container Flows

Year	Loaded outflows	Empty outflows	Loaded inflows	Empty inflows	Outbound empty share	Inbound empty share	Total-flow imbalance
2012	11.60	5.93	15.85	1.97	33.8	11.0	1.60
2013	11.71	6.09	16.23	1.91	34.2	10.5	1.88
2014	11.58	6.94	17.33	1.70	37.5	8.9	2.70
2015	11.07	8.66	18.28	1.44	43.9	7.3	-0.03
2016	11.45	8.22	18.87	1.42	41.8	7.0	3.11
2017	11.79	9.67	20.34	1.34	45.1	6.2	1.05
2018	12.06	10.35	21.62	1.48	46.2	6.4	3.01
2019	12.08	10.95	21.51	1.49	47.5	6.5	-0.16
2020	11.44	10.98	21.83	1.37	49.0	5.9	3.46
2021	10.95	15.05	25.50	1.18	57.9	4.4	2.62
2022	10.60	15.78	25.26	1.08	59.8	4.1	-0.13
2023	10.70	12.23	22.09	1.17	53.3	5.0	1.43
2024	11.05	14.45	25.15	1.19	56.7	4.5	3.25

Note: Loaded and empty flow measures are national aggregates from the balanced 2012–2024 port panel and are reported in millions of TEU. Empty shares are reported as percentages of total container flows in the corresponding direction. The total-flow imbalance is defined as total inflows less total outflows, divided by average total flows across both directions.

Table A.2 summarizes monthly national aggregates for the balanced port panel. The table reports the distribution of loaded flows, empty flows, total flows, empty-container shares, and total-flow imbalances. These statistics show that empty outflows are a large and persistent share of outbound U.S. container traffic, while inbound empty shares are comparatively small. They also show that total inbound and outbound flows are close to balanced once loaded and empty containers are considered together.

Table A.3 reports annual national loaded and empty container flows. These annual aggregates show the evolution of empty-container reliance over time while preserving the aggregation level used in the descriptive evidence. The table also reports the total-flow imbalance, defined as the difference between total inflows and total outflows relative to average two-way total flows.

Table A.4 reports empty-share moments by period. These benchmarks help mo-

Table. A.4. Historical Empty-Share Benchmarks

Period	Mean out. empty share	Med. out. empty share	P25 out. empty share	P75 out. empty share	Mean in. empty share	Mean total-flow imbal.	Months
2012–2016	38.08	38.48	34.04	42.09	9.01	3.12	60
2017	44.94	44.94	42.89	47.37	6.23	2.56	12
2018–2019	46.74	48.07	44.51	49.72	6.47	3.12	24
2020–2021	53.10	54.81	49.44	58.13	5.28	3.70	24
2022–2024	56.50	55.74	53.68	60.12	4.58	3.27	36

Note: The table reports monthly national empty-share moments by period using the balanced 2012–2024 port panel. Outbound and inbound empty shares are measured as empty TEU divided by total TEU in the corresponding direction. The total-flow imbalance reports the absolute difference between total inflows and total outflows as a percentage of average two-way total flows.

Table. A.5. Grouped Port-Role Summary Statistics

Port group	No. ports	Mean monthly thruflow	Mean net in.	Mean net in. share	Mean out. empty share	Mean in. empty share
Large gateway ports	4	2.23	0.07	3.38	57.24	2.78
Mid-tier ports	8	1.43	-0.04	-3.18	30.76	13.75

Note: The table reports grouped monthly averages for the balanced 2012–2024 port panel. Large gateway ports are Los Angeles, Long Beach, NWSA, and Port of NY \& NJ; remaining ports in the balanced panel are grouped as mid-tier ports. TEU quantities are reported in millions. No port-month observations are reported.

tivate the moderate counterfactual target used in the main text. In particular, the pre-trade-war and pre-pandemic period provides a natural historical reference point for the empty-container outflow share. The counterfactual target of 40 percent should therefore be interpreted as a return toward the pre-shock historical status quo, rather than as a literal statutory threshold.

Table A.5 provides grouped evidence on port specialization. Rather than reporting port-level observations, ports are grouped into large gateway ports and mid-tier ports. This table documents that large gateway ports account for substantial throughflow and tend to operate as net inflow locations, while mid-tier ports play a larger role in absorbing national equipment imbalances through net outflows. This grouped evidence supports the interpretation that the U.S. port system collectively reallocates equipment across locations, rather than each port operating as an isolated bilateral round trip.

V. Unilateral and Port-Specific Results

In this section, I address alternative specifications that mirror those proposed in the main body of this study. Table A.6 depicts the co-movement between empty container units and trade flows traveling in the same direction for a given year-month, between the US and RoW. I find no relationship, suggesting that only opposite-leg variation in trade flows stimulates systematic adjustments to empty container repositioning.

Tables A.7 & A.8 mirror national regressions. Generally, these findings are weaker, which is due to ports not individually maintaining balanced container flows. Across ports, the US maintains national responsiveness to adjustments in the trade balance

Table. A.6. Empty Container Elasticity w.r.t. Trade Flows (kg)

Dependent Variable: Empty Container Flows (TEU)	ln(Outbound)		ln(Inbound)	
Model:	(1)	(2)	(3)	(4)
ln(Inbound Trade)	1.574***		-0.2355	
	(0.0937)		(0.2149)	
ln(Outbound Trade)		0.1257		0.5921***
		(0.1023)		(0.1560)
n-obs	156	156	156	156
Within R^2	0.64	0.004	0.02	0.09

Clustered (month) standard errors in parentheses. Codes: ***: 0.01, **: 0.05, *: 0.1. US empty container flows are regressed on US containerized trade flows, expressed in terms of kilograms. For example, a one percent increase in the weight of 'Inbound Trade' is associated with a 1.57% rise in outbound empty container flows. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

and opposite-end responsiveness in container movements.

Table. A.7. (Ports) Trade Flow Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows	Outbound		Inbound	
Model:	(1)	(2)	(3)	(4)
Export/Import (USD)	-0.1164**			
	(0.0529)			
Export/Import (kg)		-0.0702*		
		(0.0346)		
Import/Export (USD)			-0.0065*	
			(0.0031)	
Import/Export (kg)				-0.0138***
				(0.0032)
Mean Dep. Var	37.1%		14.3%	
Mean Regressor	0.469	0.828	3.03	1.59
n-obs	1,872	1,872	1,872	1,872
Within R^2	0.04	0.06	0.01	0.02

Clustered (port) standard-errors in parentheses. Codes: ***: 0.01, **: 0.05, *: 0.1. Examines variation in empty containers as a share of total container outflows, given the variation in the skewness of the trade balance. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

Table. A.8. (Ports) Empty Container Elasticity w.r.t. Opposite-Direction Trade Flows

Dependent Variable: Empty Container Flows (TEU)	Outbound		Inbound	
Model:	(1)	(2)	(3)	(4)
ln(Imports, USD)	0.7775*** (0.1077)			
ln(Imports, kg)		0.5252** (0.1713)		
ln(Exports, USD)			0.1988 (0.1612)	
ln(Exports, kg)				-0.0207 (0.3118)
n-obs	1,872	1,872	1,872	1,872
Within R^2	0.16	0.13	0.001	0.005

Clustered (port) standard-errors in parentheses. Codes: ***: 0.01, **: 0.05, *: 0.1. Each variable is log-transformed. The regression results portray the elasticity of total US empty container flows concerning opposite-direction US containerized trade flows expressed in terms of deflated USD (value) and by total weight (kilograms). All models include port-year, port-month, and year-month fixed effects.

VI. Solution Method and Model Calibration

To establish a baseline set of exogenous parameters, I first calibrate model primitives and then estimate the remaining set of unknowns using an exactly identified method-of-moments calibration approach. For a given ij round trip containerized shipping route, the set of unknown exogenous parameters ρ is equal to $\left(a_{ij}, a_{ji}, w_i, w_j, \tau_{ij}, \tau_{ji}, c_{\underset{ij}{\leftrightarrow}}, r_{\underset{ij}{\leftrightarrow}}\right)$ and price elasticity, ϵ.

For wages, I use an OECD index of monthly manufacturing income growth rates and the International Labor Organization (ILO) annual measure of monthly manufacturing income levels, which are available for a subset of trade partners. For tariffs, I use the UNCTAD Trade Analysis Information System (TRAINS) database on effective manufactured goods' tariff rates, all of which are reported across US trade partners.[34] I deflate the value of trade flows and USD-converted wage levels for each trading partner using the Bureau of Labor Statistics Consumer Price Index for all urban consumers, which considers all final good items less food and energy, averaged across major US cities.[35] Lastly, I include an estimate of the annual price elasticity of demand provided by Wong (2022) that is specific to containerized trade. I assume $\hat{\epsilon} = 12.6$ is common across individual trade routes.[36]

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[34] Upon joining http://wits.worldbank.org/, select 'Advanced Query' and then the 'Tariff and Trade Analysis' subsection. I use the SITC 4 product group labeled 'manufactures' and the effective tariff rate measure.

[35] Consumer Price Index for All Urban Consumers: All Items Less Food and Energy in U.S. City Average [CPILFESL], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/CPILFESL, November 1st, 2022.

[36] I have tested the sensitivity of my results using a monthly trade elasticity estimate of 20.96, more appropriate for a model featuring intertemporal dynamics. The qualitative results of this

Using calibrated parameters and country-level endogenous trade outcomes, represented by $Y^{\text{data}} = \{X_{ij}, X_{ji}, \hat{l}_{ij}, \hat{l}_{ji}\}$, I estimate the remaining set of unobserved preference parameters and route-specific per unit handling costs of containers, $\{a_{ij}, a_{ji}, c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\}$, via method of moments. I minimize the objective function,

$$R = \text{dist}' \times \bar{W} \times \text{dist}, \tag{21}$$

where dist represents the log difference in vectors of 'observed' and model-guess trade outcomes between the US and a given trade partner, $\log(Y^{\text{data}}) - \log(Y^{G})$, and $\bar{W}$ is a weight matrix that assists in speeding the identification of $\tilde{\rho}$. I use measures from 2017 to estimate these parameters of underlying long-run primitives of containerized trade. This choice of year avoids concerns that the China-US trade war or period of COVID-related port congestion could introduce. Given that for each round trip, I estimate four unknowns across a system of four equations, my model is just-identified and I exactly match the observed trade values and estimated loaded container flows.

VII. Loading Factor Estimates & Container Flow Diagnostics

While I allow commodity-specific loading factors to vary by directional flow, I have also aggregated across low-volume commodity types to observe how costly reducing regressors are in terms of accuracy. As displayed in Table A.11d, I compare the national container flows predicted by varying specifications relative to a time series of observed loaded container flows. The most accurate results are obtained by estimating loading factors for specific commodities by direction (separately) across panel data sets of export and import activity. Additionally, the 'Full' and 'Union' sets of regressors perform best, of which more details are provided in the notes section of the table. I use the 'Full – Separately' approach for this paper to generate country-specific container flows.[37] As highlighted in Tables A.9a and A.9b, models which include port and year fixed effects yield the lowest root-mean-square error (RMSE) scores. These scores compare predicted and observed US – East Asian and US – European container flows, where the measure of interest is the ratio of bilateral loaded container unit flows. For East Asia, geographic groupings perform similarly to loading factors which vary only by commodity. For Europe, the standard approach of commodity-specific loading factors delivers the most accurate results. Considering both regions

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robustness exercise did not materially change.

[37] Alternative specifications for regressors have been evaluated concerning loading factors that vary across spatial– and income–based groupings. Although neither of these specifications are used for the main results of this paper, their associated results are available upon request.

jointly, I proceed use no arbitrary country groupings for estimated loading factors.

Table. A.9. RMSE of Loaded Container Flow Ratios

Panel A: US-E. Asia (Pacific)

Country Grouping	Coef Filter	Products	none	p	p+y	p+m	py	pm	py+m	ym+p	pm+y	p+y+m
Geographic	None	Agri+Manu	0.388	0.346	0.200	0.528	0.204	0.707	0.291	0.366	0.511	0.342
No Groups	None	Agri+Manu	0.058	0.408	0.224	0.574	0.180	0.908	0.240	0.314	0.695	0.359
Geographic	Directional	Agri+Manu	4.740	0.303	0.271	0.346	2.582	0.342	2.512	0.527	0.674	0.315
Income-based	None	Agri+Manu	0.240	0.423	0.335	0.584	0.231	0.777	0.361	0.505	0.724	0.487
No Groups	Directional	Agri+Manu	2.353	1.154	1.022	1.138	1.773	0.324	1.868	0.833	0.301	0.978
No Groups	None	Manufacturing	3.073	1.812	1.550	1.999	2.469	2.183	2.753	1.551	1.807	1.675
Geographic	None	Manufacturing	4.523	1.845	1.704	1.954	2.788	1.929	3.033	1.794	1.768	1.793
Income-based	None	Manufacturing	2.415	2.063	1.905	2.215	2.706	1.994	3.021	2.094	1.842	2.037
Income-based	Directional	Agri+Manu	3.952	2.718	2.642	2.307	2.598	0.870	3.042	1.808	0.976	2.224
Geographic	Directional	Manufacturing	8.346	2.877	2.735	2.860	6.314	2.616	6.019	3.231	3.496	2.723
No Groups	Directional	Manufacturing	5.422	4.087	3.693	4.038	5.552	2.327	5.207	3.083	2.110	3.579
Income-based	Directional	Manufacturing	8.192	6.129	5.537	6.377	7.118	6.067	8.141	6.212	6.208	5.876

Panel B: US-European (Atlantic)

Country Grouping	Coef Filter	Products	none	p	p+y	p+m	py	pm	py+m	ym+p	pm+y	p+y+m
No Groups	None	Manufacturing	2.130	0.056	0.064	0.045	0.110	0.126	0.216	0.070	0.166	0.055
No Groups	None	Agri+Manu	0.932	0.083	0.071	0.122	0.151	0.070	0.217	0.081	0.046	0.080
No Groups	Directional	Manufacturing	1.640	0.064	0.111	0.170	0.236	0.089	0.321	0.055	0.090	0.091
No Groups	Directional	Agri+Manu	1.636	0.208	0.262	0.292	0.447	0.125	0.495	0.191	0.106	0.221
Income-based	None	Agri+Manu	1.593	0.337	0.401	0.207	0.625	0.183	0.507	0.244	0.218	0.218
Income-based	None	Manufacturing	2.632	0.268	0.420	0.097	1.063	0.070	0.939	0.219	0.111	0.207
Geographic	None	Manufacturing	1.605	0.454	0.545	0.355	1.850	0.320	1.787	0.197	0.335	0.432
Geographic	Directional	Manufacturing	2.236	0.866	0.866	1.021	0.853	0.594	0.427	1.563	0.058	0.309
Geographic	Directional	Agri+Manu	2.337	0.938	0.911	1.045	0.907	0.818	0.564	1.445	0.237	0.373
Geographic	None	Agri+Manu	4.920	1.131	0.965	1.024	1.591	1.381	1.491	0.652	1.111	0.831
Income-based	Directional	Manufacturing	1.984	0.824	0.996	0.772	0.657	0.577	0.623	0.697	0.685	0.875
Income-based	Directional	Agri+Manu	2.288	1.033	1.168	0.874	0.740	0.397	0.685	0.757	0.498	0.932

Country Groupings includes (i) No grouping, (ii) Geographic (Asia/Oceania, Europe, South America and Africa/Middle East, and (iii) Income-based (four quartiles based on each country's average GDP per capita between 2012 and 2021). Coef Filter includes (i) None – no corrections to estimated loading factors, and (ii) Directional – replaces negative loading factors with their opposite-direction counterpart for the same country-group, if the opposite-direction coefficient is of a a lower value. Products represent measures generated using either (i) Agri+Manu – the entire set of commodity weight flows listed in the data set, or (ii) Manufacturing – the 72 manufactures featured at the HS2 level, as defined on the TRAINS product grouping 'manufactures' set.

VIII. The European Customs Union and Container Flows

Of the many European countries featured in the baseline scenario of this paper, Austria, the Czech Republic, Hungary, and Switzerland represent inland regions that could only be accessed by US containerized trade via third-party coastal channels (e.g. Rotterdam, Antwerp). Each of these countries is part of the European Customs Union. Due to the frictionless nature of trade and the apparent interdependence of countries regarding port access, I treat the EU Single Market as a single trade partner.

Using quarterly Eurostat container flow data, I find that the European Customs Union region acts as a balanced container redistribution system only after cross-country aggregation. When regressing the log of total container inflows from the rest of the world (all non-EU countries) on the log of total container outflows, I fail to reject the null hypothesis of a one-for-one exchange in container units. Crucially, this finding requires the inclusion of empty container units. This evidence and approach are isomorphic to the empirical evidence of balanced container exchanges in the US (Table 3). However, due to the constrained time frequency of the data, this exercise relies on a smaller sample size. In contrast, individual European countries maintain imbalanced container flow systems at the national level (Figure A.1). This pattern of local imbalances is strikingly similar to the heterogeneous roles played by individual US ports which, only when combined, maintain a balanced redistribution system of bilateral container flows.

Table. A.10. (EU) Balanced Container Exchanges with non-EU partners

Dependent Variable:	Total Container Inflows (TEU)
Model:	(1)
Total Container Outflows	0.8577***
	(0.1194)
n-obs	73
Within R^2	0.53

Clustered (year) standard-errors in parentheses. Codes: ***: 0.01, **: 0.05, *: 0.1. Each variable is log-transformed. The regression results portray the elasticity of total European container inflows given opposite-direction container outflows. I feature year and quarter fixed effects to capture time-specific and seasonal shocks that may temporarily offset balanced container exchanges.

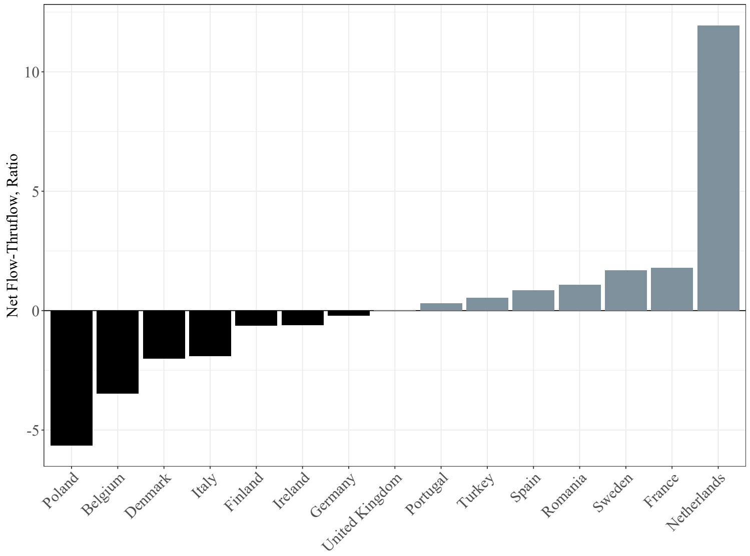

Figure A.1. European Specialization by Net Flow Status (2017)

Note: The net flow to thruflow ratio uses inflows less outflows of loaded and empty container units divided by the total flow of loaded & empty container unit traffic. This 2017 data is sourced from “Volume of containers transported to/from main ports by direction, partner entity, container size, and loading status", extraction ID: MAR_GO_QM.

Table. A.11. Directional Loading Factor Estimates

Panel A: Joint Estimates

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	F.E.
0.145	0.199	19	62.361	85.625	26.39	none
0.078	0.108	21	62.208	85.414	29.17	port
0.125	0.171	21	61.769	84.812	29.17	year
0.126	0.172	22	60.240	82.712	30.56	mon
0.077	0.106	22	60.553	83.142	30.56	p+y
0.077	0.105	23	59.150	81.216	31.94	p+m
0.126	0.173	21	61.769	84.812	29.17	y+m
0.071	0.098	18	63.910	87.751	25.00	py
0.127	0.174	22	59.969	82.340	30.56	ym
0.078	0.107	23	60.485	83.049	31.94	pm
0.067	0.091	20	61.062	83.842	27.78	py+m
0.074	0.102	21	60.600	83.207	29.17	ym+p
0.076	0.105	23	58.985	80.989	31.94	pm+y
0.057	0.078	16	64.163	88.099	22.22	pym
0.075	0.103	23	60.330	82.836	31.94	p+y+m

Panel B: Import-Specific

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	F.E.
0.199	0.229	18	71.492	82.449	25.00	none
0.119	0.137	3	86.318	99.546	4.17	port
0.152	0.175	19	70.990	81.869	26.39	year
0.150	0.173	19	71.276	82.199	26.39	mon
0.114	0.132	2	86.410	99.653	2.78	p+y
0.120	0.139	3	86.318	99.546	4.17	p+m
0.152	0.175	19	70.990	81.869	26.39	y+m
0.114	0.131	2	86.139	99.340	2.78	py
0.153	0.176	20	70.976	81.854	27.78	ym
0.119	0.137	4	83.897	96.754	5.56	pm
0.113	0.131	2	86.477	99.730	2.78	py+m
0.115	0.132	2	86.410	99.653	2.78	ym+p
0.114	0.131	4	82.490	95.132	5.56	pm+y
0.115	0.133	2	86.410	99.653	2.78	p+y+

Panel C: Export-Specific

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	F.E.
0.080	0.150	18	45.637	85.852	25.00	none
0.071	0.133	4	48.449	91.142	5.56	port
0.064	0.121	13	48.464	91.169	18.06	year
0.064	0.121	13	48.464	91.169	18.06	mon
0.072	0.136	4	48.449	91.142	5.56	p+y
0.069	0.129	4	48.449	91.142	5.56	p+m
0.064	0.121	13	48.464	91.169	18.06	y+m
0.062	0.117	0	53.158	100.000	0.00	py
0.065	0.123	10	48.685	91.584	13.89	ym
0.068	0.129	4	48.449	91.142	5.56	pm
0.059	0.111	0	53.158	100.000	0.00	py+m
0.070	0.133	5	48.442	91.127	6.94	ym+p
0.071	0.134	5	48.423	91.093	6.94	pm+y
0.071	0.133	4	48.449	91.142	5.56	p+y+m

Panel D: Performance Diagnostics by Methodology

Method	In-RMSE	In-Corr	Out-RMSE	Out-Corr
Full | Jointly	56,638.14	0.980	39,092.72	0.775
Full | Separately	31,520.21	0.993	17,796.20	0.958
Intersect | Jointly	76,182.46	0.973	66,964.02	0.397
Intersect | Separately	34,837.47	0.992	19,368.11	0.951
Union | Jointly	60,875.81	0.979	48,363.68	0.658
Union | Separately	30,748.43	0.994	17,887.69	0.957

Note: Column (1) reports trade value weighted average of loading factor coefficients. Column (2) reports the same measure limited to manufactured goods. Column (3) reports the number of negative manufacture coefficients estimated. Column (4) reports the non-negative manufacture coefficients' share of total trade flows. Column (5) reports the non-negative manufacture coefficients' share of manufacture trade flows. Column (6) reports the negative coefficient count as a percentage of the manufacture coefficient count. Column (7) lists the associated fixed effects used. Diagnostics details: 'Full' uses the entire set of HS2 product types. 'Intersect' uses a subset of HS2 products that represent the top 50 highest commodity-specific shares of total export weight and total import weight. The resulting commodity set is the intersection of common commodities between these two shortlists. 'Union' uses the full set of top 50 commodities, rather than their intersection. RMSE columns denote root mean square error and Corr columns list the correlation of each measure, relative to observed total container inflows and outflows.

IX. Non-Labor Production Costs

The baseline calibration uses observed monthly manufacturing wages as the production-cost shifter in the delivered-price equation. This approach preserves the tractability of the model and allows the cost side to be disciplined by publicly available country-level data. However, the non-transport value embodied in a representative containerized shipment is not determined by wages alone. Shipment values also reflect intermediate inputs, capital intensity, markups, product composition, and other production costs that are not directly observed in the baseline calibration. This appendix evaluates whether the main counterfactual results are sensitive to this simplified mapping from observed wages to non-transport costs.

I augment the baseline price equations with route-direction production-cost conversion factors, B_{ij} and B_{ji}:

$$p_{ij} = B_{ij} w_i \tau_{ij} + T_{ij}, \qquad p_{ji} = B_{ji} w_j \tau_{ji} + T_{ji}.$$

These parameters should not be interpreted as labor requirements alone. They convert observed monthly manufacturing wages into a broader non-transport shipment-cost component that absorbs intermediate inputs, capital costs, markups, and route-specific product composition.

Introducing B_{ij} and B_{ji} adds two route-specific unknowns, in addition to $\rho = \{a_{ij}, a_{ji}, c_{ij}, r_{ji}\}$. I discipline these additional parameters using bilateral transport and insurance margins from the OECD International Transport and Insurance Costs of Merchandise Trade (ITIC) database. The ITIC data report ad valorem transport and insurance costs, or CIF–FOB margins, defined $\frac{CIF-FOB}{CIF}$, where CIF denotes the import value inclusive of cost, insurance, and freight, and FOB denotes the value of the good excluding international transport and insurance costs. The OECD constructs these measures primarily from explicit import records in which both CIF and FOB valuations are reported at detailed product levels, and then uses a gravity-based estimation procedure to fill missing country-partner-product-year observations (Miao and Wegner, 2022). The resulting database provides bilateral estimates of transport and insurance costs as a percentage of CIF import value.

I map these OECD margins into the model by targeting the model-implied transport-cost shares, $\frac{T_{ij} l_{ij}}{X_{ij}}$, and $\frac{T_{ji} l_{ji}}{X_{ji}}$. These ratios express transport costs as a share of delivered trade value and are therefore the model analogues of the OECD CIF–FOB margins. The augmented calibration uses six route-specific moments. Bilateral trade values, estimated loaded-container flows, and bilateral transport-cost shares.

This exercise should be interpreted as a robustness check rather than a replacement for the baseline calibration. The OECD ITIC margins are the closest available bilateral source for ad valorem transport and insurance costs, but they are not specific to maritime containerized shipping. The database covers merchandise trade generally, combines direct reported margins with model-based estimates, and captures total transport and insurance costs rather than the separate loaded-handling and empty-repositioning components of those costs. As a result, the augmented calibration is useful for evaluating whether the paper's main counterfactual results depend on the wage-only scaling of non-transport costs, but it is not designed to replace the baseline estimates of empty-container handling costs.

Table A.12 reports the results. The central conclusion is preserved. Under the augmented calibration, the moderate ECO quota reduces total containerized trade value by approximately 8.3 percent and shipping capacity by approximately 18.8 percent, magnitudes very close to the baseline estimates of 8.2 percent and 18.5 percent. The composition of adjustment changes somewhat, with the export response now smaller, while import prices rising by a larger margin. Allowing for broader non-labor production costs makes the export-expansion effect more conservative, but does not overturn the main finding that restricting empty-container repositioning reduces aggregate trade activity and shipping capacity.

Table. A.12. Robustness to Non-Labor Production-Cost Conversion Factors

Specification	Imports	Exports	Imp. Price	Exp. Price	Value	Vol.	Capacity	Imp. CIF	Exp. CIF
Baseline ECO quota	-17.1	30.0	2.3	-5.7	-8.2	-4.3	-18.5	–	–
Production-cost conversion	-14.8	20.5	6.0	-9.0	-8.3	-5.2	-18.8	1.1	-1.7

Note: Entries report percentage changes from the 2017 baseline, except for the final two columns, which report percentage-point changes in transport and insurance costs as a share of trade value. The augmented calibration introduces route-direction production-cost conversion factors, B_{ij} and B_{ji}, and disciplines them using OECD bilateral transport and insurance margins. Because the OECD margins cover all transport modes rather than maritime container services alone, this exercise is interpreted as a robustness check rather than a replacement calibration.

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