Unconventional Protectionism in Containerized Shipping

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Abstract

Containerized shipping operates similarly to a bus system, where vessels service round trip routes between origin-destination pairs. 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 of balanced bilateral container traffic – only when accounting for empty container repositioning. Motivated by the Ocean Shipping Reform Act of 2022, I structurally estimate 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

Approximately 70% of international trade values travel via maritime transport, two-thirds of which is attributed to containerized shipping (Notteboom et al., 2022). These services specialize in providing round trip transport, where ports are routinely visited back and forth between specific origin-destination combinations. Containers are repositioned within these continuous loops of transport services, creating a persistent circulation of transport equipment. In cases of imbalanced demand and asymmetric shipping volumes, repositioning includes empty containers, which ensures the sustainability of prevailing global trade imbalances. This phenomenon introduces the *empty container repositioning problem* for transport operators – a need to relocate empty containers on the low-volume leg of a given round trip, from net importer countries back to net exporter countries (Song, 2021). The repositioning of empty containers is estimated to represent 20% of total ocean container movements and 15% of fleet management costs (Drewry, 2006; Rodrigue, 2020). Repositioning influences transport intermediaries' costs, which feeds into allocated vessel capacity, freight rate pricing, and trade outcomes on round trip routes. Although container repositioning has been well-documented in the maritime logistics literature (Crainic et al., 1993; Lee and Song, 2017; Song, 2007), little is known of how frictions in container availability affect trade outcomes. The recent passing of the Ocean Shipping Reform Act, henceforth OSRA22, embodies a rare example of a restriction to container repositioning. This bill limits the extent to which transport operators can refuse leasing vessel capacity to US containerized exporters in favor of transporting additional empty container units.

In this paper, I examine container repositioning under round trip trade and quantitatively evaluate how policy restrictions to empty container outflows, such as OSRA22, may influence US trade outcomes. My main findings suggest that empty container repositioning is key in maintaining existing trade imbalances and access to greater effective transportation capacity. When empty repositioning is restricted in favor of stimulating domestic exports, shipping supply declines, which in turn leads to added inflationary pressure and an overall reduction in bilateral trade activity.

I first build a quantitative model of round trip trade based on Armington (1969), which is capable of featuring both balanced and imbalanced exchanges of goods, and includes a richer specification of endogenous trade costs. A representative exporter faces both the domestic cost of producing a good and the freight rate issued by a transport operator. The transport operator maintains bilateral round trip services between the two countries. Price setting for these services accounts for differences in demand between regions and partly reflects the cost of repositioning empty containers on the low-volume leg of a given round trip. Should the cost of handling empty container units rise, a transport operator lowers their exposure to trade volume asymmetries through bilateral freight rate adjustments and reduced shipping capacity. From the perspective of a net importer country, such as the US, the model predicts that when the import-export ratio rises, resulting empty container traffic as a proportion of total outbound container units must rise too.

Using novel port-level loaded & empty container traffic data[1], I empirically examine the validity of these comparative statics and establish three key facts; (i) the scale of the empty container repositioning problem grows as asymmetries in shipping volumes intensify, (ii) balanced exchanges of national bilateral flows of total container flows are evident only when accounting for empty container repositioning across these US ports, and (iii) the relative size of a port determines its role in supporting balanced container exchanges – large ports such as L.A. & New York generate persistent net inflows of containers while mid-tier US ports are sources of net outflows. Findings (ii) and (iii) suggest that the US maintains an interdependent container repositioning system between US ports and the hinterland, indicating a reliance on the accessibility of intermodal transport. Only upon a national aggregation across US ports does the model's constraint of a balanced container flow network appear evident.

In preparing a quantitative analysis of OSRA22, I combine my measures of container traffic with US census data on monthly port-level bilateral containerized trade flows (by product type, value, and weight) and auxiliary country-level data. This allows me to calibrate and estimate model primitives of the baseline scenario of my model through a two-stage estimation strategy.

The first stage estimates bilateral loaded container flows between US ports and the main trading partners of the US. This is achieved by exploiting variation in metric tonne weights of 2-digit Harmonized System (HS2) goods shipped on these same trade routes across each year-month of the sample. Suppose that for a given shipping lane, there is a marginal increase in the metric tonnes of a product's weight. Given that each container maintains a weight capacity, a greater amount of a given good suggests an increased number of containers allocated for transport. Furthermore, the rate at which each product's weight increases total container count usage varies due to the volume constraint each container represents. For example, a metric ton of sheet metal likely

[1]This balanced panel represents over 80% of US container throughput for 2012–2021.

takes up far less volume in a container unit compared to a metric ton of furniture. By estimating each product's "loading factor" – the rate at which weight contributes to loaded container flows – I recover origin-destination loaded container flows between US ports and key US trade partners. I provide evidence of a striking fit between country-specific estimated loaded container flows and UNCTAD data of East Asian–North American and European–North American bilateral loaded container traffic.

The second stage uses a Generalized Method of Moments (GMM) approach to recover four model primitives for each shipping route – the underlying pair of preference parameters each country's consumer base maintains for their trade partner's manufactured goods, as well as per-unit costs of handling empty and loaded container units. The remaining primitives are calibrated using a combination of public data sourced from the International Labor Organization, OECD, and World Bank. Estimated primitives align well with what is known about shipping. For example, depending on the lane, my estimate of empty container handling costs varies between 14.9% and 21.3% of total fleet management costs, which is rather close to the 15% share reported in Rodrigue (2020). Furthermore, implied freight rates are consistently higher on the higher-volume lanes of a given round trip, as established in Hummels et al. (2009).

To capture the intent of OSRA22's unconventional trade policy, I consider the effects of an empty container outflow (ECO) quota, which effectively reallocates vessel space towards US exporters. I consider a moderate regime, where the policymaker seeks to return to a status quo represented by the 40% historical average of empty containers as a percentage of total container outflows originating from the US. Restricting the return of empty transport equipment meets the sole objective for higher exports for the US policymaker, but conflicts with the broader interests of the public once accounting for the full round trip effect. Constraining repositioning contributes to an 18.6% decline in round trip shipping capacity, a 17.7% decline in containerized imports, and an 8.5% reduction in the total value of containerized trade.

To the best of my knowledge, this paper is the first to provide empirical evidence of the effect of empty container repositioning in round trip transport services on trade outcomes. Additionally, the micro-founded model of this paper enables the assessment of a relatively modern and unique trade policy concern, represented by OSRA22. The results of this paper contribute to several strands of the literature.

First, this paper adds to the international trade literature on endogenous trade costs. Transport costs represent an increasingly prominent factor in determining overall trade costs. For example, 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,[2] more recent theoretical frameworks use a variety of endogenous approaches (Irarrazabal et al., 2015; Hayakawa et al., 2020; Bonadio, 2022). Atkin and Donaldson (2015), Brancaccio et al. (2020), and Ignatenko (2023) use differences in market power across intermediary transport service operators for variation in transport costs. Allen and Arkolakis (2022) and Wong and Fuchs (2022) highlight how the quality of infrastructure and traffic congestion across regions can also explain variation in transport costs. Using bilateral container traffic data at the port level, I document how the cost of servicing imbalanced trade routes through empty container repositioning affects round trip trade flows.

Secondly, this paper is closely related to studies focused on particular facets of maritime transport. These technological and logistical innovations play important roles in influencing key economic outcomes. Bernhofen et al. (2016) suggests container technology introductions between 1962-1990, on average, contributed to an 85% higher trade ten years later. Brooks et al. (2021) highlights how container technology led to substantial population and employment growth in US counties near containerized ports. Following the 2016 Panama Canal expansion, Heiland et al. (2022) estimates an average increase in trade of 9-10% across affected shipping lanes. Ganapati et al. (2021) provides evidence of logistical hubs known as *entrepôts* fostering advancements in vessel technology and size, which lowered transport costs. Carreras-Valle (2022) shows that technological innovations reduced internationally-sourced input costs.[3] 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 aforementioned benefits of containerization. Furthermore, routes that maintain particularly high asymmetries in trade volume, such as shipping lanes between the US and China or Japan, are far more exposed to the malaise effects of intervention in empty repositioning.

Third, this paper adds to the literature examining resurgent trade protectionism. Such decisions are largely a reflection of the state of policymakers' underlying constituent bases, which are subject to adverse developments in social identification patterns (Grossman and Helpman, 2021; Bombardini et al., 2023). Whiile protectionism

[2]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).

[3]These cost-saving measures also coincided with greater precautionary inventory management and higher delivery time volatility.

often leads to welfare losses (Sampson, 2017; Fajgelbaum et al., 2020; Bown, 2021; Fajgelbaum and Khandelwal, 2022), infant industries may find themselves on more favourable growth trajectories (Juhász, 2018). Our understanding of these policies is often limited to cases of demand-side interventions (e.g., tariffs and quotas). This paper instead focuses on supply-side elements of trade policy in which the use and availability of transport equipment in constrained strategically. I find that this new tool is precise in targeting net exporters, particularly those with a greater reliance on empty containers, which may raise concerns with governing bodies, such as the WTO, that seek to limit the use of discriminatory trade 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. The 'backhaul' freight rate drops 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 pricing on highway toll lanes (Williamson, 1966; Cooks and Li, 2023).

The remainder of the paper proceeds as follows. In the next section, detail the factors that contribute to empty container repositioning and outline a partial equilibrium model of containerized trade. Section 3 provides a brief description of 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). I include three representative agents: consumers, producers and transport operators. Endogenous transport costs are a function of per-unit loaded and empty container handling costs. I first briefly detail facts known of the industry, then outline key assumptions and solve the model. Lastly, I establish a set of comparative statics that explain variation in empty repositioning.

2.1 Background

Since the emergence of container technology, this form of transport equipment has grown to become a worldwide norm. As Levinson (2016) explains, 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 in international trade, 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 out to a given destination than those that make their way back from the net importer. To accommodate required container inventory across ports, container repositioning features empty units on the backhaul (lower volume) leg of a given round trip. In essence, this behaviour reflects an inventory management problem in which a cost-minimizing assignment of container capacity and flows must be determined.[4]

Lee and Song (2017) highlight two considerations that transport operators face under imbalanced round trips; (i) a quantity decision − firms decides 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 moved from one node to another Song and

[4] 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.

Dong (2015). The goal of this decision is to satisfy flow balancing, where container flows between two nodes should be equal. Additionally, uncertainties are considered in inventory control models to produce decision-making rules that dynamically determine the amount of empties in and out of a node. I feature empty container costs in freight rate setting and enforce a balanced container flow constraint between nodes. However, I do not feature decision-making rules for short-term uncertainty.

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 $\overset{\leftrightarrow}{ij}$ denotes a round trip that services trade between countries i and j. Consumers in country j are endowed with one unit of labor that is supplied elastically, exhibit a love of variety across consumable goods and are geographically immobile. A representative 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.[5] Heterogeneous countries maintain route-specific preference parameters, a_{ij}, for each tradeable variety. A single unit of a good is associated with one unit of transport equipment utilized. Therefore, l_{ij} is equivalent to the number of loaded containers shipped from i to j. The price elasticity of demand, ϵ, is common across varieties and routes.

Producers are perfectly competitive and produce variety j using labor. I assume goods' prices from i to j increase through three components; (i) the domestic wage, w_i; (ii) the tariff of the given ij leg, τ_{ij}; and (iii) the per-container freight rate, T_{ij}.[6]

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

Intermediary transport operators are perfectly competitive and service a given bilateral trade route, $\overset{\leftrightarrow}{ij}$. The profit maximization problem for the transport operator servicing route $\overset{\leftrightarrow}{ij}$ is a joint-profit function that considers the optimal bundle of container inputs. This is a variation of the joint-profit function featured in Behrens and Picard (2011),

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

[6] 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.

in which I add a balanced container flow constraint.

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

Revenue generated from servicing route $\overleftrightarrow{ij}$ is the sum of each leg's respective freight rate times the loaded container quantity. Costs are determined the states of container inputs used to provide services. Costs of loaded and empty container handling are represented by the set $\{c_{ij}, c_{ji}, r_{ij}, r_{ji}\}$.[7] I assume that empty containers are cheaper to handle.[8] Bilateral flows of container units, irrespective of their state, are balanced, which implies vessels operate at full capacity. Next, I depict the profit maximization problem under *weakly* imbalanced trade. In the case of balanced trade, Eq. (3) is subject to a constraint of equivalent bilateral flows of loaded container units and the empty container redistribution problem is nonexistent. The resulting system of equations conforms with the balanced trade scenario featured in Wong (2022).

2.3 Weakly Imbalanced Trade

Suppose country j is a weak net importer of route $\overleftrightarrow{ij}$, where $l_{ij} \geq l_{ji}$. This leads to a prevailing empty redistribution problem, and the profit function is subject to a balanced container flow constraint, $l_{ij} = l_{ji} + e_{ji}$, where maximum 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

$$\max_{\{l_{ij},l_{ji},e_{ji}\}} \pi_{\overleftrightarrow{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - c_{ij}l_{ij} + c_{ji}l_{ji} - r_{ji}e_{ji} \quad (4)$$
$$\text{s.t. } e_{ji} = l_{ij} - l_{ji}$$

Upon substituting the balanced container constraint into the profit maximization problem, freight rates for both legs of a given round trip $\overleftrightarrow{ij}$ are determined. Due to the

[7] 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).

[8] 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.

price-taking nature of this perfectly competitive transport operator, prices are underpinned by the marginal costs of container redistribution.

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

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 $\overleftrightarrow{ij}$, 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. (6) into the demand function for imported varieties,

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

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.

$$e^*_{ji} = \left(\frac{\epsilon}{\epsilon-1}\right)^{-\epsilon} \left(\frac{1}{a_{ij}}^{-\epsilon} (w_i\tau_{ij} + c_{ij} + r_{ji})^{-\epsilon} - \frac{1}{a_{ji}}^{-\epsilon} (w_j\tau_{ji} + c_{ij} - r_{ji})^{-\epsilon}\right) \tag{7}$$

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

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

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 $\overleftrightarrow{ij}$, reflected by l^*_{ij}, declines.

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 $\epsilon > 1$:

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

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

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

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.

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

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

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

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 simply 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 manage. In response, firms must exhibit a widening of 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.

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

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

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

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

$$\epsilon\left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ji}}\right)^{-\epsilon}(w_j\tau_{ji} + c_{ji} - r_{ji})^{-\epsilon-1} < 0$$

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 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_{ji}, reduces the scale 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.

$$E_{ji}^* = \frac{e_{ji}^*}{l_{ji}^* + e_{ji}^*} = 1 - \left(\frac{a_{ji}}{a_{ij}}\right)^{\epsilon}\left(\frac{w_i\tau_{ij} + c_{ij} + r_{ji}}{w_j\tau_{ji} + c_{ji} - r_{ji}}\right)^{\epsilon} \tag{9}$$

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,

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

Using Eq. (9) and (10), 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 ($\Delta E_{ji} > 0$).[9]

3 Data

The main data set of the paper combines monthly US port samples of containerized trade and associated container traffic flows, both for empty and loaded units. Auxiliary tariff and wage data are used for the calibration of exogenous parameters throughout the counterfactual analyses of this study.

3.1 Containerized Goods

I use monthly trade data from the US Census Bureau, which details port-level imports and exports of containerized goods by value, weight, and respective trade partner. The sample begins in January 2003 and provides commodity-level stratification at the six-digit Harmonized System (HS6) level. I form a balanced panel of the top 14 port locations for containerized trade flows.[10] In cases of port alliances, I assume that port

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

[10] 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),

infrastructure is jointly utilized between ports. The ports of Seattle & Tacoma as well as New York & Newark are each combined into two unique port authorities, the NWSA and PANYNJ, respectively.

3.2 Container Unit Traffic

Using containerized goods data, I developed an informed shortlist of top containerized US ports. I approached each respective port authority individually and received monthly 20-foot equivalent unit (TEU)[11] traffic flow data in four separate series: (i) inbound loaded containers, (ii) outbound loaded containers, (iii) inbound empty containers, and (iv) outbound empty containers. To my knowledge, this is the first study in international economics to document and use novel empty container repositioning data. Unlike containerized goods flows, I do not observe the origin or ultimate destination of container traffic flows. To ensure a balanced and representative panel of data, I have limited container traffic flows to those observed between January 2012 and December 2021 of twelve key ports, which represents approximately 80% of national container unit thruflows. For more details on the wider time series of port data, see Appendix II.

3.3 Auxiliary Data

For the quantitative exercises detailed in Section 6, 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.[12]

Tacoma (WA), Baltimore (MD), New Orleans (LA) and Jacksonville (FL).

[11] A 40-foot intermodal container is counted as two TEUs.

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

4 Stylized Facts

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. *A positive deviation in country j's export-import ratio with country i is correlated with a negative deviation in the volume of empty container units shipped from j to i as a share of total container units shipped from j to i.*

Eq.(9) and Eq.(10) imply that a higher export-import ratio of a net importer implies lower empties as a percentage of total container outflows. As US imports from a net exporter country rise ($X_{ji}/X_{ij} \downarrow$), the asymmetry in trade volumes between these two countries grows, which implies that the logistical burden in servicing imbalanced trade – through the repositioning of empty container units – has grown ($E_{ji} \uparrow$).

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

Given no data on bilateral US container flows, I aggregate across US ports and I test this negative relationship empirically through variation in trade and container flows between the US (j) and the rest of the world (i),

$$E^*_{jit} = \alpha + \beta\left(\frac{X^*_{jit}}{X^*_{ijt}}\right) + \mu_{jit} \quad , \quad E^*_{ijt} = \alpha + \beta\left(\frac{X^*_{ijt}}{X^*_{jit}}\right) + \mu_{ijt}, \tag{12}$$

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 redistribution. This highlights adjustments in the empty repositioning burden that transport operators face, given the variation in bilateral trade volumes across round trips. In Table 2, I use the Net-Gross ratio featured in Brancaccio et al. (2020), and observe further support for this proposed relationship between the prevailing trade imbalance and the size of the empty container redistribution problem.

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)	-0.9575***			
	(0.0687)			
Export/Import (kg)		-0.3909***		
		(0.0288)		
Import/Export (USD)			-0.0253***	
			(0.0062)	
Import/Export (kg)				-0.0327***
				(0.0097)
Mean Dep. Var	43.51%		7.47%	
Mean Regressor	0.322	0.711	3.143	1.427
n-obs	120	120	120	120
Within R^2	0.58	0.68	0.30	0.15

Heteroskedasticity-consistent 'White' standard-errors. Codes: ***: 0.01, **: 0.05, *: 0.1. Examines variation empty containers as a share of total container outflows, given variation in the skewedness 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)
$\left(\frac{\text{Net Exports}}{\text{Gross Trade}}\right)^{\text{USD}}$	-0.8510***		0.2322***	
	(0.0703)		(0.0428)	
$\left(\frac{\text{Net Exports}}{\text{Gross Trade}}\right)^{\text{KG}}$		-0.5756***		0.1121***
		(0.0514)		(0.0308)
Mean Dep. Var	43.51%		7.47%	
Mean Regressor	-0.514	-0.172	-0.514	-0.172
n-obs	120	120	120	120
Within R^2	0.57	0.65	0.37	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 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.

Examining the robustness of these results in Appendix III, 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.

4.2 Balanced Container Flows

Stylized Fact 2. *A positive deviation in container units transported from i to j is proportionately matched by the change in container units transported from j to i.*

Thus far I have shown that trade balances are strongly indicative of the scale of the empty container repositioning. Upon aggregating across US ports, evidence suggests that national levels of container inflows and outflows appear largely balanced, but only when accounting for empty container repositioning. This lends strong support for the balanced container flow constraint, which underpins my partial equilibrium model of empty container repositioning. In Table 3, I regress inbound container traffic on outbound container traffic at the national level. These results suggest that a system of balanced container exchanges exists even within a given month of containerized transport, as highlighted by the reported coefficient not statistically differing from 1 at a 99% confidence level. In contrast, when focusing on only loaded container exchanges, a far more commonly reported measure of container traffic at the port level, this balance in the exchange of transport equipment is left completely obscured.

Table. 3. Balanced National Container Flows

Dependent Variable: ln(Inbound Container Flows)			
Model:	Total (1)	Loaded (2)	Empty (3)
ln(Outbound Container Flows, Total)	1.012***		
	(0.0210)		
ln(Outbound Container Flows, Loaded)		-0.0913	
		(0.2841)	
ln(Outbound Container Flows, Empty)			-0.4641***
			(0.0314)
Observations	120	120	120
Within R^2	0.94	-0.007	0.62

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.

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.[13]

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

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 the largest ports in the US function as net inflows of total containers, while mid-tier-sized ports act as net outflows of total container units. This suggests that interdependence exists across ports, which maintains balanced container flows at a national level. To the best of my knowledge, these statuses across ports have not yet been documented in the transport economics literature. In Figure 1, 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.

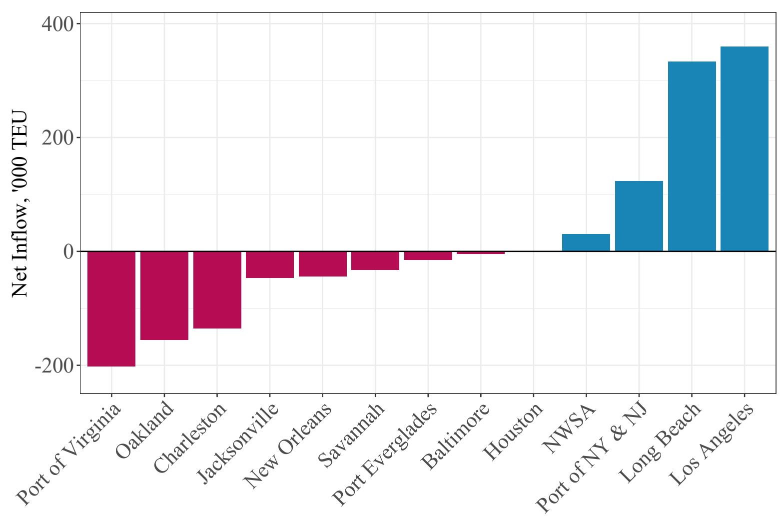

Figure 1. Port Specialization by Net Inflow Status (2017)

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 2, 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

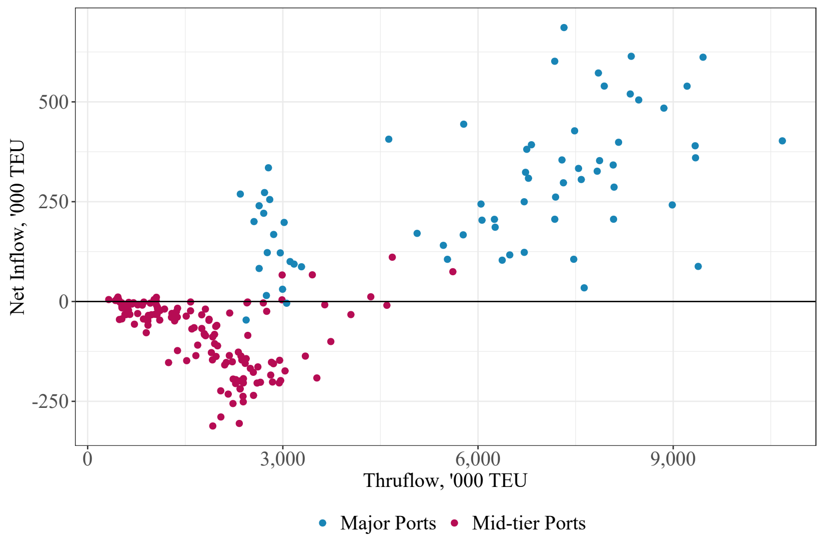

Figure 2. Port Specialization by Total Container Thruflow (2012-2021)

between port hubs in order to exploit lower per-unit transport costs (Ganapati et al., 2021). 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). Upon examining average vessel sizes between these port groups, I find that larger vessels arrive at net inflow ports (Table 4).

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.

Given that national bilateral container flows are balanced, yet individual ports specialize, I suggest that container ports are interdependent with respect to 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. While some container units may return to their US port of origin, my findings suggest that many units of equipment depart from the US through alternative ports around the country, particularly through mid-tier-sized ports. This detail is key in motivating my counterfactual analysis of balanced container flow trade at the country rather than port level.

5 Counterfactual

I use the empty repositioning model featured in Section 3 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 key set of restrictions and assumptions necessary to yield the most compelling fit to UNCTAD regional container traffic data and proceed with calibrating and estimating model primitives. Upon establishing this multi-country baseline scenario, I introduce the counterfactual policy measure – an empty container outflow (ECO) quota, applied through a specific per-unit tax on outgoing empty containers.

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 $\{a_{ij}, a_{ji}, c_{\underset{ij}{\leftrightarrow}}, r_{\underset{ij}{\leftrightarrow}}\}$ by calibrating observable parameters based on a trade-weighted average of tariffs on manufactures, a trade-weighted average of monthly manufacturing wages, and an elasticity of demand of 20.96 estimated using monthly data by Wong (2022).[14] 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 roundtrip, I use the generalized method of moments (GMM) estimator alongside Equations (7) and (8), to exactly identify each set of unknown model primitives.[15] I set observed containerized trade

[14]See Appendix section IV 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.

[15]I assume that loaded and empty handling costs of a given round trip are both invariant by

values, $\{X_{ij}, X_{ji}\}$, and estimated loaded container traffic, $\{\hat{l}_{ij}, \hat{l}_{ji}\}$, to average monthly 2017 levels to adhere to the time frequency at which ϵ was estimated. This choice of year avoids any complications that later periods associated with the China-US Trade War and COVID-19 epidemic would introduce.

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.[16]

5.2.1 Assumptions

Container units include a set of operational characteristics that define the maximum weight that 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.[17] 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. As Holmes and Singer (2018) demonstrates, the binding constraint for a given container unit is almost always volume, rather than weight. Differences in the dimensionality of products 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,

$$l_{pt}^f = \sum_{j=1}^{J} l_{pjt}^f = \sum_{j=1}^{J} \sum_{k=1}^{K} \beta^{fjk} w_{pjkt}^f, \;\; f \in \{\text{Imports}, \text{Exports}\}, \tag{13}$$

direction, which yields two input prices to estimate per round trip route.

[16] 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.

[17] 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.

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

$$l^f_{US-j,t} = \sum_{p=1}^{P} l^f_{pt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \beta^{fjk} w^f_{pjkt}, \tag{14}$$

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

$$l^f_{pt} = \sum_{k=1}^{K} \beta^{fk} \sum_{j=1}^{J} w^f_{pjt} + \varepsilon^f_{pt} \tag{15}$$

For a given commodity, the use of available volume capacity may differ on either leg of a round trip, leading to differences in commodity-specific loading factors. While restricting loading factors β to be invariant by direction f would double the associated observation count of this exercise and allow me to exploit wider variation in commodity-specific volumes, this restriction may also 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.[18]

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

[18]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 Appendix V and generally contribute little towards improving loading factor estimates.

5.2.2 Loading Factor Estimates

Under these assumptions, I regress Eq.(15) 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 3).[19]

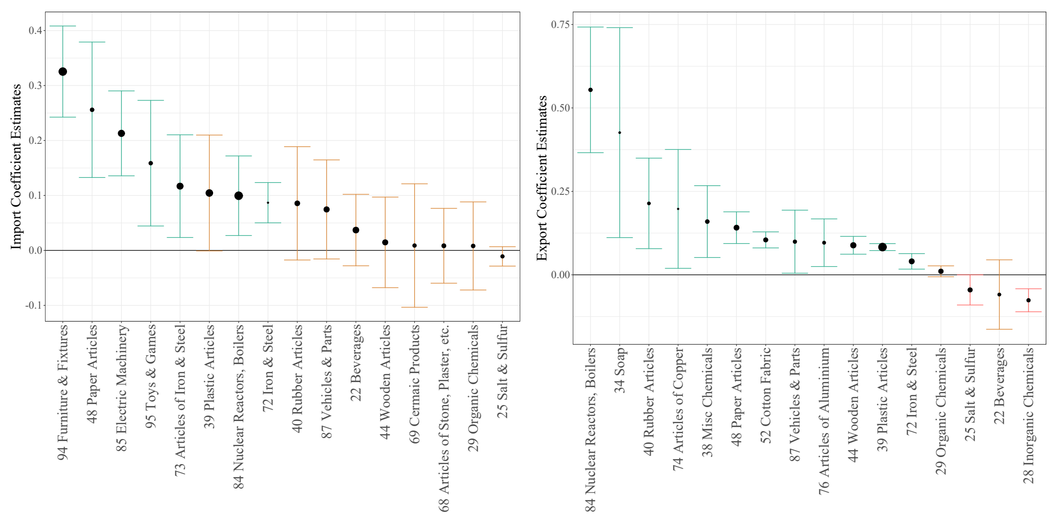

Figure 3. Loading Factor Estimates by Commodity

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 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,

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

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.

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

5.2.3 Container Flow Estimates

To determine which fixed effects yield the best match and quantify differences in performance, I compare estimated volumes and bilateral ratios of loaded container flows to UNCTAD records of annual loaded containers exchanged on US-East Asian & US-European routes (UNCTAD, 2022). While the loading factors and resulting country-level container flow estimates are available across a wide range of countries, I limit the use of these estimates to the subset of countries that report manufacturing wage measures needed for model calibration between 2012 to 2021. Additionally, I introduce balanced container flow system that incorporates the entire European Single Market and exclude both Mexico and Canada due to land borders with the US potentially limiting the degree to which bilateral flows of containerized trade are fully serviced by maritime transport operators.[20] Upon accounting for product and multi-country constraints, I generate loaded container flow estimates specifically for manufactured goods across countries featured in Figure 4. This limits my use of multi-country estimated bilateral container flows to represent 70% (50%) of containerized import (export) value.

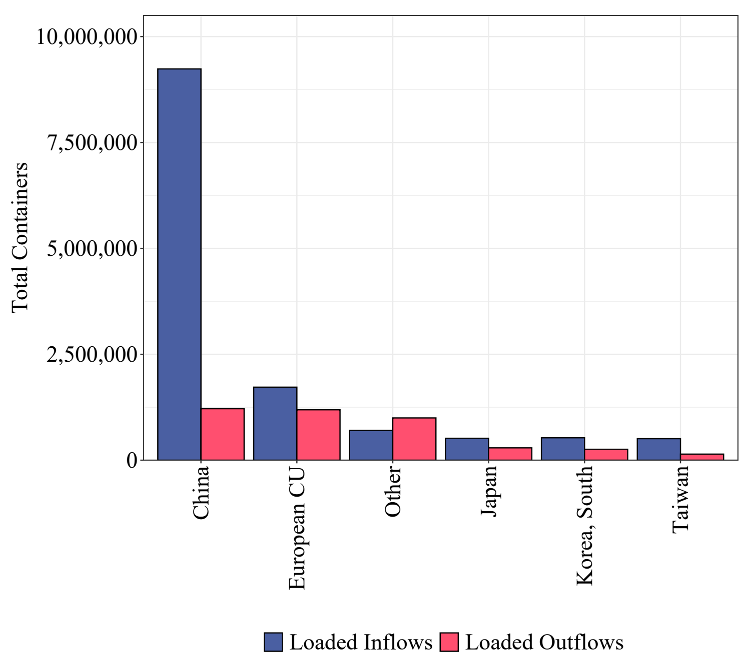

Figure 4. Estimated Container Flows by Country and Direction

Note: These estimates of manufactured goods flows across US trade partners represents 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.

[20]See Appendix VI 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. I contrast the asymmetries in loaded container flows to observed in each of these regions to patterns documented by the UNCTAD and find a compelling fit (Figure 5). 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.

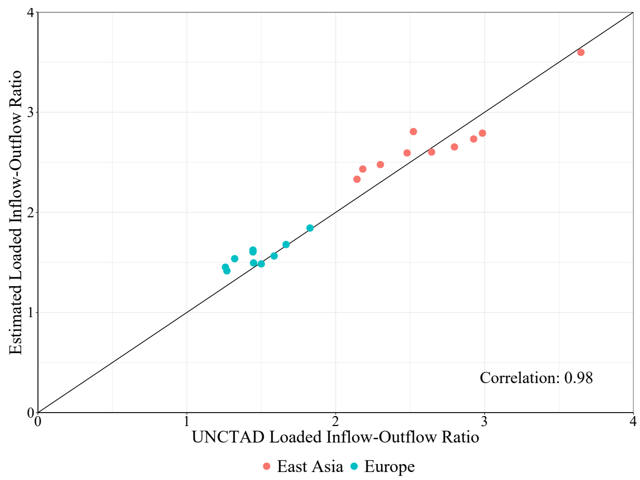

Figure 5. Model Fit – Loaded Container Ratios by Region (2012-2021)

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 loaded container estimates in a GMM estimation, I assess the following untargeted features and moments in the baseline model; (1) the empty container redistribution share of container fleet management costs averages between 14.9–21.3%, depending on the given year, which places US-related costs of empty container redistribution relatively 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) using marginal costs of handling loaded, $c_{\underset{ij}{\leftrightarrow}}$, and empty container flows, $r_{\underset{ij}{\leftrightarrow}}$, implied freight rates are greater for portions of US round trips that feature a full set of loaded containers, which is reflective of 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 regulation through OSRA22, which limits 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 tax rate.

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, for every five containers that entered the US laden with goods, three containers left the US empty. 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. However, the increased difficulty for exporters in securing 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. This bipartisan 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

This bill has since entered into public law as of June 16th 2022. However, the bill did not specify how this restriction on prioritizing empties must be imposed and instead delegated this task to the Federal Maritime Commission (FMC). The challenge for the FMC involves defining cases of 'unreasonable refusals of vessel capacity' and then it must devise measures by which to punish any violators.[21]

In place of the effective policy, I consider a counterfactual exercise that embodies policymakers' intent of limiting empty redistribution in favor of greater capacity allocation towards US exporters. I introduce a per-unit tax on empty container outflows to the model, where the tax rate (γ) is calibrated to target a capped share of empties as a percentage of total container outflows. I use a moderate 'status-quo' target of the US historical share, 40% of container outflows.[22]

5.5 Main Results

As displayed Table 5, a moderate ECO quota stimulates export activity. US exporters flock to relatively cheaper freight rates for round trip services to net exporter countries, which results in a substitution from empty container redistribution to additional loaded container servicing. The US containerized trade deficit, represented by the import-export ratio, also declines by 37.3%. However, a focus only on this outbound leg of US round trip transport ignores further market developments, known as round trip effects, which may also be of interest to the policymaker.

Table. 5. Disaggregated Counterfactual Outcomes

U.S. Measures	Imports	Exports	Imp. Price	Exp. Price	Value	Vol.	Capacity
Δ%	-17.7	31.1	1.7	-4.3	-8.5	-4.4	-18.7

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.

Relative to the baseline scenario, a multi-country model of US containerized trade sees a 17.7% decline in the real value of imports. This is attributed to the greater cost

[21] The FMC has since issued a Notice of Proposed Rulemaking (NPRM), which has suggested that 'unreasonable' refusals must be determined on a case-by-case basis (FMC, 2022). To judge reasonability, the FMC would require that ocean common carrier provide a documented export strategy that enables the efficient movement of export cargo.

[22] I have also examined an 'extreme' ECO quota, in which $\gamma_{\bar{E}_{ji}=0}$ is targeted and the practice of empty container redistribution is eliminated. Similarly to the main results described in the next section, I find that the policy backfires, as reflected by the associated decline in vessel capacity on net exporter trade routes and reduction in overall trade value and volume.

associated with returning the empties, which passes through entirely to the price of US imports under this perfectly competitive setting. As a result, the price of imported goods rises by 1.7% while US exporters see their goods' prices decline by 4.3%. The overall capacity of TEU services for round trips between the US and individual countries declines by 18.6% due to policy introducing an added friction servicing imbalanced volumes of trade. This leads to a reduction in container redistribution. The scale of the empty container redistribution problem as a percentage of total US container outflows falls by 37.4%.

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 8.5% (4.4%) 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 6, East Asian trade partners maintained the highest empty container shares in the predefined baseline scenario. Upon the introduction of a per-unit tax on empty repositioning, these particularly asymmetric trade routes faced the greatest contractionary pressure.

The sizable loss in transport equipment accessibility and the acuteness of this decline on routes with particularly high dependencies on empty repositioning leads to noteworthy changes in country shares of the US import market. As displayed in Figure 7, in some cases net exporters gain market shares despite being reliant on empty container repositioning. China, which receives approximately four empty returns for every five loaded containers shipped to the US, suffers a two percentage point loss in its share of containerized US imports. Given Europe's relatively weaker dependency on empty container repositioning, although imports do decline, the overall decline in total US containerized imports of manufactures falls by a greater margin. This results in the European Customs Area developing a larger share of overall US imports, despite being negatively affected by an ECO quota.

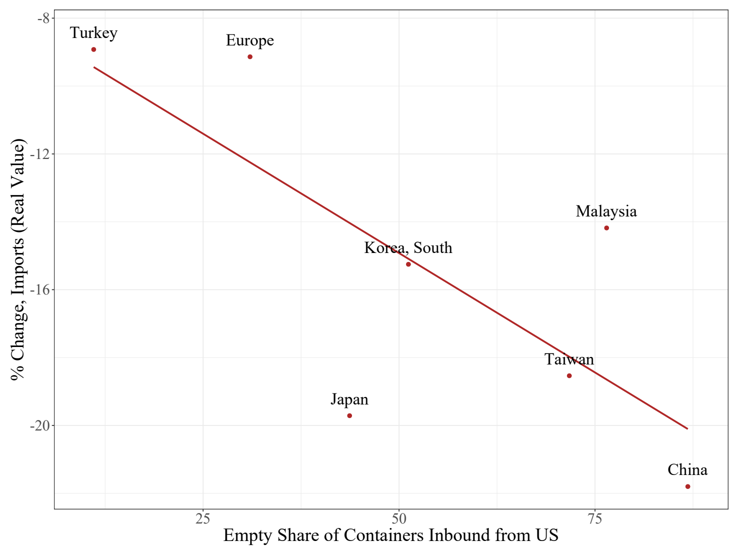

Figure 6. US Import Value by Net Exporter (2017)

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.

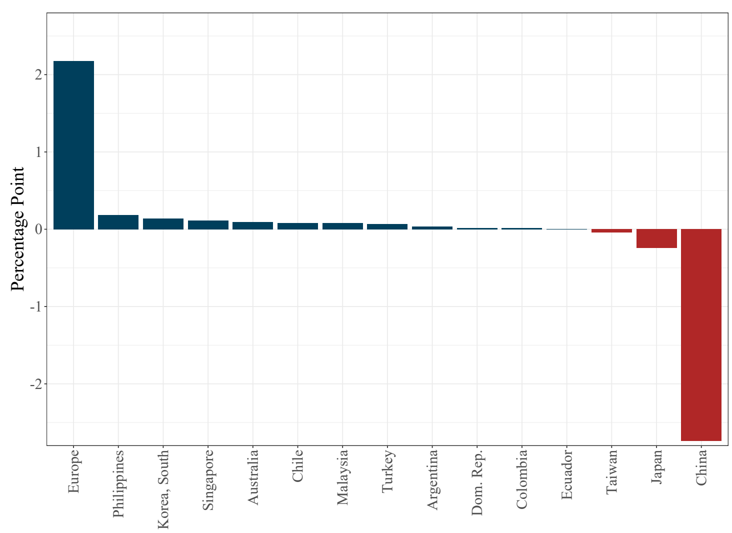

Figure 7. Change in Trade Partner Shares of US imports (2017)

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

6 Conclusion

This paper provides a quantitative approach towards understanding the novelties of containerized trade and its reliance on container repositioning. I identify how variation in transport equipment availability influences trade outcomes on opposite leg portions of round trips, adding to means by which one can incorporate endogenous transport costs into models of trade. In this particular case, I internalize the cost of repositioning container units generally faced by transport operators and highlight how variation in such costs determines prevailing trade imbalances between origin-destination pairs. I use novel container traffic data, representative of 80% of gross container unit traffic, to connect this theory to empirics. I document a round trip effect taking place in which adjustments in the prevailing trade balance of the US, through larger trade deficits, enlarge the scale of the empty container repositioning. Opposite-leg trade outcomes drive variation in the empty container repositioning problem of the US.

I also contribute theoretically to the literature of international trade and transport economics through my partial equilibrium model of container repositioning. This model yields positive bilateral freight rates under a setting of perfectly competitive transport operators with perfect knowledge, which as highlighted by Demirel et al. (2010), normally introduces unintuitive and troublesome model predictions. By representing container units physically in the joint profit maximization problem of transport operators, I circumvent a persistent challenge in modeling imbalance round trip trade in which the lower volume leg of a given route yields a freight rate of zero. This challenge is not unique to maritime commerce and can be considered applicable across multiple modes of transport.

Lastly, I quantitatively evaluate how interfering with the use of this transport technology affects trade flows. Although studies of trade conventionally consider protectionism to occur through adjustments to tariff rates, goods quotas, and other means of applying non-tariff measures, little is understood of how policymakers' targeting of transport equipment could influence trade outcomes. This supply-side trade policy is motivated by the recently passed Ocean Shipping Reform Act of 2022 (OSRA22), in which restrictions to empty container outflow activities were introduced in an effort to stimulate US exports. My findings suggest that government intervention in the repositioning of empty container units may lead to unanticipated and adverse effects, in which overall vessel capacity servicing the US reduces due to the relatively greater expense associated with servicing trade imbalances. Within trade lanes, exports grow, but this minor boon are outscaled by a reduction in import activity by approximately 133bn USD (0.68% of GDP) and increased price inflation for US consumers. Great care should be taken in considering the joint-effects of liner shipping regulation, rather than focusing on an export lane of round trip traffic in isolation. 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."

Appendix

I. General Equilibrium with Homogeneous Input Prices

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

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

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, imbalance 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.[23] 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 $\overset{\leftrightarrow}{ij}$.

III. Container Traffic Sample

In Table A.1, each row reports a given year's number of contributing ports, the total number of loaded and empty container units handled by the set of contributing ports, the total number of loaded and empty container units handled at the national level, and the sample's share of national throughput.

[23] 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.

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	42,031,000	64.53
2011	11	29,181,883	42,550,784	68.58
2012	12	35,350,843	43,538,254	81.19
2013	12	35,937,976	44,340,866	81.05
2014	12	37,548,916	46,233,010	81.22
2015	13	40,501,360	47,886,446	84.58
2016	13	41,021,434	48,436,472	84.69
2017	13	44,209,298	52,132,844	84.80
2018	13	46,619,407	54,776,341	85.11
2019	13	47,064,791	55,518,878	84.77
2020	13	46,555,563	54,963,689	84.70
2021	13	53,748,362	62,044,503	86.63

Source: National thruflows use 'Container port throughput, annual' from UNCTAD.

IV. 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.2 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.

Table. A.2. Empty Container Elasticity with Respect to Trade Flows (kg)

Dependent Variable: Empty Container Flows (TEU)				
	ln(Outbound)		ln(Inbound)	
Model:	(1)	(2)	(3)	(4)
ln(Inbound Trade)	1.582***		-0.0881	
	(0.1152)		(0.2576)	
ln(Outbound Trade)		0.0033		0.6352***
		(0.1292)		(0.1770)
n-obs	120	120	120	120
Within R^2	0.65	2.89×10^{-6}	0.002	0.13

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 1.58% rise in outbound empty container flows. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

Tables A.3 & A.4 mirror national regressions. Generally, these findings are weaker, which is due to ports not individually maintaining balanced container flows. Across ports, the US maintain national responsiveness to adjustments in the trade balance and opposite-end responsiveness in container movements.

Table. A.3. (Ports) Trade Flow Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows	Outbound		Inbound	
Model:	(1)	(2)	(3)	(4)
Export/Import (USD)	-0.0847*			
	(0.0412)			
Export/Import (kg)		-0.0582*		
		(0.0278)		
Import/Export (USD)			-0.0063*	
			(0.0033)	
Import/Export (kg)				-0.0124***
				(0.0027)
Mean Dep. Var	34.6%		15.27%	
Mean Regressor	0.496	0.901	2.865	1.499
n-obs	1,440	1,440	1,440	1,440
Within R^2	0.03	0.06	0.01	0.02

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

Table. A.4. (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)	0.6218***			
	(0.1256)			
ln(Imports, kg)		0.3348**		
		(0.1339)		
ln(Exports, USD)			0.4949*	
			(0.2278)	
ln(Exports, kg)				0.3210*
				(0.1464)
n-obs	1,440	1,440	1,440	1,440
Within R^2	0.064	0.044	0.01	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 with respect to 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.

V. 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 a Generalized Method of Moments (GMM) 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.[24] I deflate the value of trade flows and USD-converted wage levels for each trade 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.[25] Lastly, I include an estimate of price elasticity of demand provided by Wong (2022) and specific to containerized trade, where $\hat{\epsilon} = 20.96$ is assumed to be common across individual trade routes.

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, $\{a_{ij}, a_{ji}, c_{\underset{ij}{\leftrightarrow}}, r_{\underset{ij}{\leftrightarrow}}\}$, via GMM.[26] I minimize the objective function,

$$R = \text{dist}' \times \bar{W} \times \text{dist}, \tag{16}$$

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 specific year allows me to avoid any complications or concerns that the use of data from the proceeding 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.

VI. 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

[24]Upon establishing a login for http://wits.worldbank.org/, select 'Advanced Query' and then the 'Tariff and Trade Analysis' subsection. I use the SITC 4 product group labelled 'manufactures' and the effective tariff rate measure.

[25]U.S. Bureau of Labor Statistics, 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.

[26]The respective outcome variables used are observed average monthly containerized imports & exports (USD value) and estimated loaded container inflows and outflows.

regressors in terms of accuracy. As displayed in Table A.6d, I compare the national container flows predicted by varying specifications relative to a time series of observed loaded container flows. Estimating loading factors for specific commodities by direction (separately) across panel data sets of export and import activity yields the most accurate set of results. 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.[27] As highlighted in Tables A.5a and A.5b, 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 jointly, I proceed with using no arbitrary country groupings for estimated loading factors.

Table. A.5. 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, iff the opposite-direction coefficient is of a a lower value. Products represents measures generated using either (i) Agri+Manu – the entire set of commodity weight flows listed in the data set, or (ii) Manufacuturing – the 72 manufactures featured at the HS2 level, as defined on the TRAINS product grouping 'manufactures' set.

[27] 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.

VII. The European Customs Union and Container Flows

Many of the countries featured in the multi-country baseline scenario of this paper are European. Of those countries, Austria, the Czech Republic, Hungary and Switzerland represent inland regions which could only be accessed by US containerized trade via third party coastal channels such as the ports of the Rotterdam or Antwerp. Each of these countries is also part of the European Customs Union. Due to the frictionless nature of trade and apparent interdependence of countries with respect to port access, I treat the EU Single Market as a single trade partner entity. Eurostat container flow data suggests that only upon cross-country aggregation does the European Customs Union region function as a balanced container redistribution system. In contrast, individual European countries which form this union 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.

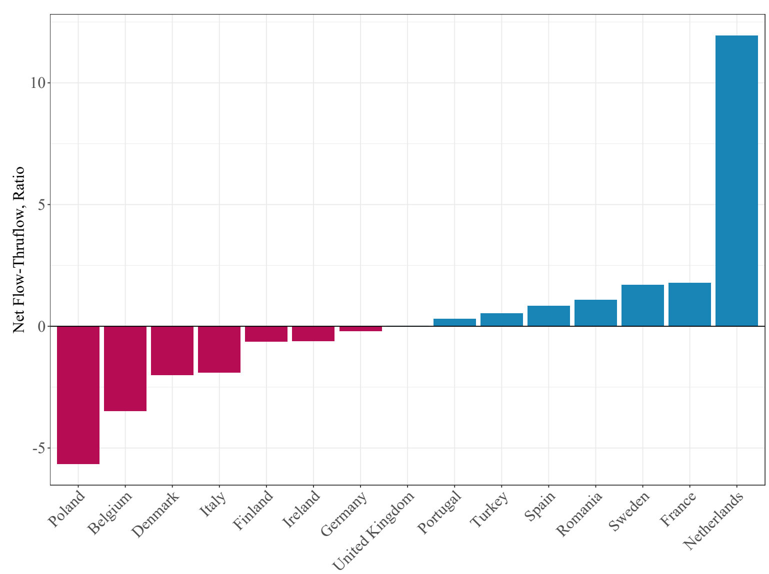

Figure A.1. European Specialization by Net Flow Status (2017)

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.6. 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 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.

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