Unconventional Protectionism in Containerized Shipping*

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Abstract

The containerized shipping market operates similarly to a bus system, where vessels maintain round trip transport services between origin-destination pairs. Transport operators must commit to sufficient shipping capacity, while accounting for possible bilateral shipping imbalances. To ensure necessary transport equipment availability, vessel owners reposition empty container units on the low-volume leg of a round trip, back from import-oriented origin locations to export-oriented destinations. I provide evidence of bilateral US container traffic being consistently balanced – only when accounting for empty container unit flows. I also document a positive relationship between the US trade deficit and the scale of the empty container redistribution problem. Motivated by the US recently passing the Ocean Shipping Reform Act of 2022, I explore the effects of a restriction to empty container outflows in favor of stimulating US exports. This form of policy intervention backfires, leading to elevated import prices, contractions in transport capacity, and reduced trade activity. Upon accounting for differences in countries' extensive and intensive margins of reliance on empty containers originating from the US, I find evidence to suggest that these backfiring effects are particularly intense on US-East Asian trade routes.

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1. Introduction

Approximately 70% of international trade values travels 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 available transport equipment. In cases of imbalanced demand and asymmetric shipping volumes, repositioning includes empty containers. 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). This implies that variation in repositioning influences vessel-owning intermediaries' costs, which leads to changes in 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 an example of a restriction to container repositioning. Under this bill, the Federal Maritime Commission (FMC) has been tasked with *limiting* the extent to which transport operators can refuse allocating portions of vessel capacity to US exports 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 sustaining prevailing trade imbalances and existing transport capacity levels. 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, capable of featuring both balanced and imbalanced exchanges of goods, and based on Armington (1969) with a richer specification of 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 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 is predictive of the role each location plays – large ports such as Los Angeles & New York act as persistent net inflows of containers while mid-tier ports are 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 inter-modal 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 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 HS2-specific metric tonne weights of goods shipped on these same trade routes across each year-month of the sample. Suppose that for a given shipping lane, there is

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

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 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 of shipping. For example, depending on the lane, I estimate of empty container handling costs vary 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 specifically consider a moderate regime, where the policymaker seeks to return to a status-quo represented by the 40% long-run average of empty container outflows as a percentage of total container outflows originating from the US. I find that restricting the return of empty transport equipment backfires for the US policymaker. Constraining repositioning contributes to an 18.6% decline in round trip shipping capacity, a 17.7% decline in US containerized imports and an 8.5% reduction in the total value of US containerized trade. Additionally, imported inflation grows by just under 2 percentage points.

To the best of my knowledge, this paper is the first to provide empirical evidence of empty container repositioning in round trip transport services and its relationship with 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, including, (i) endogenous transport costs; (ii) empirical analyses of maritime trade & transport; (iii) studies of the determinants and effects of protectionist trade policy; and (iv) theoretical approaches towards representing round trip trade.

First, this paper adds to 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 economics outcomes. Bernhofen et al. (2016) suggests container technology introductions between 1962-1990, on average, contributed to a 85% higher trade 10 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.

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

Carreras-Valle (2022) shows that technological innovations reduced internationally-sourced input costs.[3] Through the novel container traffic data available to me, 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 intervention in empty repositioning.

Third, this paper adds to literature examining the motivation and effects of 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). While resurgent protectionism 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). While there is a well-documented understanding of how demand-side interventions influence trade outcomes (e.g., tariffs and quotas), OSRA22 relates to supply-side elements of trade by constraining the use and availability of transport equipment. This study represents the first and only paper to consider this unconventional form of protectionism. I find that although exports are stimulated by these restrictions, overall trade activity declines – suggesting that the policy is protectionist in nature and backfires for the policymaker. My results also suggest that this new tool is precise in targeting net exporters, particularly those with a greater reliance on empty containers from the US.

Lastly, this paper relates to the theoretical literature of round trip transport services. Given that the volumes of transported goods between two locations are often imbalanced, shipping capacity on the lower volume 'backhaul' route is underutilized. As Demirel et al. (2010) demonstrates, the 'backhaul' freight rate drops to zero under perfect competition and perfect information. Both Demirel et al. (2010) and Wong (2022) remedy this deviation from observed freight rates by either (i) enforcing balanced trade flows across round trips, or (ii) introducing imperfect information and a

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

matching process into the model. Ishikawa and Tarui (2018) solves for positive bilateral freight rates by introducing imperfect competition. I approach this challenge by instead using physical equipment as 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 redistributes empties. Under imbalanced trade, the marginal revenue of shipping an additional loaded container on the high-volume route is equal to the cost of handling that loaded unit plus the cost of returning one empty container. In contrast, transporting one additional loaded unit on the low-volume leg of a round trip occupies an existing empty, resulting in a freight rate equal to the loaded handling cost less the cost of returning an empty unit. Under specific assumptions, bilateral freight rates are both positive and the low-volume route maintains a relatively lower freight rate, as predicted in Hummels et al. (2009). This pricing scheme under asymmetric volumes relates closely to peak load pricing strategies featured in round trip passenger flights and the dynamic pricing on highway toll lanes (Williamson, 1966; Cooks and Li, 2023).

The remainder of the paper proceeds as follows. I detail how container redistribution operates and outline the factors which contribute to empty container redistribution. Section 3 outlines a partial equilibrium model of containerized trade.Section 4 provides a brief description of the novel data that I have collected, and Section 5 presents stylized facts of containerized trade. In Section 6, I calibrate and estimate the exogenous parameters of the empty container model and consider the counterfactual effects of government intervention aimed at limiting the outflow of empty container units from the US. Section 7 concludes.

2. 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. This challenge, starting in the late 1950s, represented ten years of negotiations in which time the industry determined that the standard containers would be 20-ft & 40-ft in length. Additionally, corner fittings used to lift individual units and interlock units together were also agreed upon. These efforts resulted in a flexible, harmonized system in which transport equipment could be freely redistributed back and forth within a given round trip. The subsequent global adoption of container technology across ports has yielded a complex network of supply chains which operates at lower costs but represents greater risks through increased uncertainty surrounding delivery times (Carreras-Valle, 2022).

Although container shipping and the repositioning of empty containers have been a long-held practice in international trade, it is important to understand why economic agents coordinate in this manner. For a transport operator, underlying bilateral levels of transport service demand within a given round trip can differ. This would contribute towards 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 for 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 inventory management problem in which a cost–minimizing assignment of container capacity and flows must be determined.[4]

Lee and Song (2017) describes two considerations that transport operators face under imbalanced round trip trade; (i) a quantity decision, in which the firm decides how many empty containers to store at each port, and when and how many to move between ports, and (ii) a cost estimation of empty repositioning, which contributes to how freight rate prices are determined. Regarding the quantity decision, Song and Dong (2015) refers to two key considerations. Upon adopting a network flow model, origin-destination based matrices specify the quantity of empty containers to be moved from one node to another. The goal of this decision is to satisfy flow balancing, where container flows between two nodes should be equal. The second item addresses uncertainties by adopting inventory control models to produce decision-making rules which dynamically determine the amount of empty repositions in and out of a node. I incorporate the associated contribution of empty container repositioning costs to freight rates and enforce a balanced container flow constraint between nodes such

[4]As Lee and Song (2017) highlights, empty container repositioning functions similarly to conventional manufacturing logistics in which firms strategically relocate their inventory in order to meet consumer demand. In the case of containerized round trip shipping, exporters consume transport services from transport operators and container units are redistributed in order 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.

that combinations of loaded and empty container units can be accounted for on the backhaul (lower volume) leg of a given round trip. However, given that I use a static model designed to evaluate long-run policy implications, I do not feature decision-making rules and uncertainty for individual firms.

The transport logistics literature therefore recognizes the scale of the empty container repositioning problem to be a product of underlying asymmetries in import demand volumes between service nodes and uncertainty surrounding vessel delivery times, inter-reliances on other modes of transport and demand volatility. For the purposes of this paper, I focus on the long-term determinants of variation in empty container repositioning, through imbalanced trade. The greater the asymmetry in loaded container flows within a given round trip, the larger the volume of empty container repositioning. Furthermore, the empty container repositioning problem should be considered a longstanding and necessary feature of containerized trade rather than a specific byproduct of recent episodes of port congestion and delays.

3. Model

In this section, I specify the empty container repositioning problem in an augmented Armington model based on Hummels et al. (2009) and Wong (2022). I include three representative agents: consumers, producers and transport operators. This trade model features endogenous transport costs, which are a function of tariffs, wages and per-unit loaded & empty container handling costs. The model is static in design and therefore features no time-dynamic elements. Any resulting steady-state equilibrium outcomes should be considered long-run in nature. I first outline the key assumptions of the model, then solve the model for both balanced and imbalanced trade scenarios. Lastly, I establish a set of comparative statics which explain variation in the empty redistribution problem.

3.1. Assumptions

I consider an international economy of round trip containerized trade that features J heterogeneous countries, where each country produces a unique variety of a tradeable good. The term $\overleftrightarrow{ij}$ denotes a round trip route 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:

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

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 inputs of labor. I assume that the price of transported goods from i to j increases through the following components; (i) the domestic wage rate, w_i; (ii) the tariff rate of the given ij leg of the round trip, 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), in which I add a balanced container flow constraint.

$$\begin{aligned} \max_{\{l_{ij},l_{ji},e_{ij},e_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} =& T_{ij} l_{ij} + T_{ji} l_{ji} - c_{\overset{\leftrightarrow}{ij}}(l_{ij} + l_{ji}) - r_{\overset{\leftrightarrow}{ij}}(e_{ij} + e_{ji}) \\ \text{s.t. } & l_{ij} + e_{ij} = l_{ji} + e_{ji} \end{aligned} \tag{3}$$

Revenue generated from servicing route $\overset{\leftrightarrow}{ij}$ is the sum of each leg's respective freight

[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.

rate times the loaded container quantity. Costs are determined by loaded and empty states of container inputs used to provide services. The costs of per-unit loaded and empty container handling is represented, respectively, by the set $\{c_{\overleftrightarrow{ij}}, r_{\overleftrightarrow{ij}}\}$.[7] Due to equidistant travels across routes ij and ji and the minimal attention that incoming empty containers $\{e_{ij}, e_{ji}\}$ require to be repurposed, I assume that handling costs are invariant to voyage direction and empties are cheaper to handle.[8] Bilateral flows of container units, irrespective of their state, are balanced as a result of transport operators needing to sustain container inputs on both sides of a given round trip. This constraint is affirmed in the first stylized fact in Section 3 (Figure 1).

In the following two subsections, I depict the profit maximization problem under balanced trade (Case I) and imbalanced trade (Case II). In Case I, Eq. (3) is subject to a constraint of equal bilateral loaded container flows and the empty container redistribution problem is nonexistent. In Case II, country j is the net importer of route $\overleftrightarrow{ij}$. 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 to a single value.[9] 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: $c_{\overleftrightarrow{ij}} > r_{\overleftrightarrow{ij}} \; \forall \; \overleftrightarrow{ij}$.

3.2. Case I: Balanced Trade

In this case $l_{ij} = l_{ji}$ holds, and the quantity of transport services occurring between either country is perfectly balanced. Substituting the updated production constraint into the profit maximization problem of Eq. (3), I solve for the set of equilibrium trade outcomes. Solutions for these expressions are displayed in Appendix II.

[7] Following Notteboom et al. (2022), I attribute container handling costs to the transport operator. This study highlights that operators spend, on average, 15% of fleet management costs on empty repositioning.

[8] In Appendix I, I highlight the more general case in which all container input prices are equal, regardless of state (empty/loaded) or route. Similarly to a footloose capital model featured in Behrens and Picard (2011), which examines endogenous freight rates in a round trip setting, this specification yields zero freight rates in the port of excess shipping supply. Given that I do not observe zero empty container flows, nor zero freight rates across observed data, I conclude that there must be differences input prices across containers which vary by their state.

[9] This is consistent with other imbalanced trade models under a round trip setting. For example, Ishikawa and Tarui (2018) sets service capacity to $\max\{l_{ij}, l_{ji}\}$, which in my case eliminates any empties on the larger volume leg of a round trip.

$$\max_{\{l_{ij}\}} \ \pi_{\overleftrightarrow{ij}} = T_{ij}l_{ij} + T_{ji}l_{ij} - c_{\overleftrightarrow{ij}}(l_{ij} + l_{ij}) \tag{4}$$

$$\text{FOC: } \ \frac{\partial \pi}{\partial l_{ij}} = 0 \implies T_{ij} + T_{ji} = 2c_{\overleftrightarrow{ij}}$$

Under a balanced trade assumption with constant input prices, the 'round trip' effect is present. The 'round trip' effect is defined as a phenomenon where exogenously-driven shocks to transport quantity from i to j in turn affect the transport price from j to i. Any shock to exogenous demand shifters such as consumer preferences a_{ij} or tariff rates τ_{ij} will affect every outcome variable of this partial equilibrium model. For example, should country j increase their import tariff on goods from i, such that $\Delta\tau_{ij} > 0$, this will lower j's imports as well as its exports to its trade partner. Trade protectionism backfires for the policymaker such that any attempts at inhibiting imports also limit export performance. The comparative statics of this knife-edge case – in which loaded container exchanges between nations are balanced – are analogous to Wong (2022)

Next, I outline a solution for the imbalanced trade scenario. Due to observed empty container flows across US ports, the comparative statics of this latter case are used in the empirical analysis of container traffic data.

3.3. Case II: Imbalanced Trade

Supposing that country j functions as a net importer for a given round trip, the profit maximization problem can be expressed as:

$$\max_{\{l_{ij}, l_{ji}, e_{ji}\}} \pi_{\overleftrightarrow{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - c_{\overleftrightarrow{ij}}(l_{ij} + l_{ji}) - r_{\overleftrightarrow{ij}}(0 + e_{ji}) \tag{5}$$

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

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

$$T^*_{ij} = c_{\overset{\leftrightarrow}{ij}} + r_{\overset{\leftrightarrow}{ij}} \ , \ T^*_{ji} = c_{\overset{\leftrightarrow}{ij}} - r_{\overset{\leftrightarrow}{ij}} \tag{6}$$

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 the direct per unit shipping cost, $c_{\overset{\leftrightarrow}{ij}}$, and the cost of an additional empty container on the return trip, $r_{\overset{\leftrightarrow}{ij}}$. An additional loaded container transported from j to i represents one less empty on route $\overset{\leftrightarrow}{ij}$, which implies the added cost of $c_{\overset{\leftrightarrow}{ij}}$ being partially compensated for by a cost reduction of $r_{\overset{\leftrightarrow}{ij}}$. Expressions for these bilateral freight rates can be substituted into Eq. (2).

$$p^*_{ij} = w_i\tau_{ij} + c_{\overset{\leftrightarrow}{ij}} + r_{\overset{\leftrightarrow}{ij}}, \qquad p^*_{ji} = w_j\tau_{ji} + c_{\overset{\leftrightarrow}{ij}} - r_{\overset{\leftrightarrow}{ij}} \tag{7}$$

To solve for $\{l^*_{ij}, l^*_{ji}\}$, I insert Eq. (7) into the demand function for imported varieties.

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

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

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

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

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

However, variation in empty container handling costs, $r_{\overleftrightarrow{ij}}$, 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 empty repositioning to exports, but in addition, transport capacity of route route $\overleftrightarrow{ij}$, relfected by l_{ij}^{*}, declines. Transport services on route $\overleftrightarrow{ij}$ decline due to the associated cost of maintaining imbalanced container flows.

3.4. 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 $\overleftrightarrow{ij}$. Recall for the trade value expression that we assume $\epsilon > 1$.

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

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

$$
\begin{aligned}
\frac{\partial T^*_{ij}}{\partial a_{ij}} = 0 \quad , \quad \frac{\partial T^*_{ji}}{\partial a_{ij}} = 0 \quad , \qquad \frac{\partial p^*_{ij}}{\partial a_{ij}} = 0 \quad , \quad \frac{\partial p^*_{ji}}{\partial a_{ij}} = 0 \\
\frac{\partial l^*_{ij}}{\partial a_{ij}} = \epsilon \frac{\epsilon - 1}{\epsilon} \left(\frac{\epsilon - 1}{\epsilon} a_{ij} \right)^{\epsilon - 1} \left(w_i \tau_{ij} + c_{\underset{ij}{\leftrightarrow}} + r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon} > 0 \quad , \quad \frac{\partial l^*_{ji}}{\partial a_{ij}} = 0 \\
\frac{\partial X^*_{ij}}{\partial a_{ij}} = \epsilon \frac{\epsilon - 1}{\epsilon} \left(\frac{\epsilon - 1}{\epsilon} a_{ij} \right)^{\epsilon - 1} \left(w_i \tau_{ij} + c_{\underset{ij}{\leftrightarrow}} + r_{\underset{ij}{\leftrightarrow}} \right)^{1-\epsilon} > 0 \quad , \quad \frac{\partial X^*_{ji}}{\partial a_{ij}} = 0 \\
\frac{\partial e^*_{ji}}{\partial a_{ij}} = \epsilon \frac{\epsilon - 1}{\epsilon} \left(\frac{\epsilon - 1}{\epsilon} a_{ij} \right)^{\epsilon - 1} \left(w_i \tau_{ij} + c_{\underset{ij}{\leftrightarrow}} + r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon} > 0
\end{aligned}
$$

Since these are perfectly competitive firms providing transport services, quantity supplied and freight rates are unresponsive to demand-side adjustments. However, when underlying costs of these services adjust, the corresponding freight rates charged will be adjusted uniformly. Endogenous transport costs are simply a linear function of 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 sees 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.

$$
\begin{aligned}
\frac{\partial T^*_{ij}}{\partial r_{\underset{ij}{\leftrightarrow}}} = \frac{\partial p^*_{ij}}{\partial r_{\underset{ij}{\leftrightarrow}}} \quad > 0 \quad , \quad \frac{\partial T^*_{ji}}{\partial r_{\underset{ij}{\leftrightarrow}}} = \frac{\partial p^*_{ji}}{\partial r_{\underset{ij}{\leftrightarrow}}} \quad < 0 \\
\frac{\partial l^*_{ij}}{\partial r_{\underset{ij}{\leftrightarrow}}} = -\epsilon \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}} \right)^{-\epsilon} \left(w_i \tau_{ij} + c_{\underset{ij}{\leftrightarrow}} + r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon - 1} \quad < 0 \quad , \\
\frac{\partial l^*_{ji}}{\partial r_{\underset{ij}{\leftrightarrow}}} = \epsilon \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ji}} \right)^{-\epsilon} \left(w_j \tau_{ji} + c_{\underset{ij}{\leftrightarrow}} - r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon - 1} \quad > 0 \quad , \\
\frac{\partial X^*_{ij}}{\partial r_{\underset{ij}{\leftrightarrow}}} = (1 - \epsilon) \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}} \right)^{-\epsilon} \left(w_i \tau_{ij} + c_{\underset{ij}{\leftrightarrow}} + r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon} < 0 \quad , \\
\frac{\partial X^*_{ji}}{\partial r_{\underset{ij}{\leftrightarrow}}} = (\epsilon - 1) \left(\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ji}} \right)^{-\epsilon} \left(w_j \tau_{ji} + c_{\underset{ij}{\leftrightarrow}} - r_{\underset{ij}{\leftrightarrow}} \right)^{-\epsilon} \quad > 0,
\end{aligned}
$$

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

Proposition 1. Under the assumption of 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, $r_{\underset{ij}{\leftrightarrow}}$, 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: $\frac{\partial T^*_{ij}}{\partial r_{\underset{ij}{\leftrightarrow}}} > 0$, $\frac{\partial T^*_{ji}}{\partial r_{\underset{ji}{\leftrightarrow}}} < 0$, $\frac{\partial e^*_{ji}}{\partial r_{\underset{ij}{\leftrightarrow}}} < 0$

The relationship between the scale of the empty container redistribution problem and the skewedness of the existing trade balance can be examined in a proportional manner. These expressions simplify otherwise non-linear relationships between outcome variables to a reduced linear relationship that can be taken directly to the surrounding data, should one be equipped with bilateral container traffic flows as well as containerized trade values. I represent the scale of the empty container redistribution problem with E_{ji}, which indicates the share of empties as a percentage of total container outflows from a net importer country j to net exporter i.

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

Proposition 2. Under the assumption of 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, $r_{\underset{ij}{\leftrightarrow}}$, 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: $\frac{\partial T_{ij}^*}{\partial r_{\underset{ij}{\leftrightarrow}}} > 0$, $\frac{\partial T_{ji}^*}{\partial r_{\underset{ji}{\leftrightarrow}}} > 0$, $\frac{\partial E_{ji}^*}{\partial r_{\underset{ij}{\leftrightarrow}}} < 0$

Examining the skewedness of the trade balance using an import-export ratio from j's perspective: $\frac{X_{ji}}{X_{ij}}$

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

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

4. 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.

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

Auxiliary tariff and wage data is used for the calibration of exogenous parameters throughout the counterfactual analyses of this study.

4.1. Containerized Goods

I use monthly trade data from the US Census Bureau, which details the imports and exports of containerized goods at the US port level by value and weight for each US trade partner. The available sample period begins with January 2003 and provides commodity-level stratification down the to six-digit Harmonized System (HS) level. Using this data, I form a balanced panel of the top 14 port locations for containerized trade flows.[11] In cases of port alliances, I assume that port 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.

4.2. Container Traffic

Using this informed shortlist of the top containerized US ports, I approached each respective port authority individually and retrieved monthly 20-foot equivalent unit (TEU) traffic flow data. I received four separate series: (i) inbound loaded containers, (ii) outbound loaded containers, (iii) inbound empty containers, and (iv) outbound empty containers. Unlike containerized goods flows, I do not observe the origin or ultimate destination of container traffic flows. A 40-foot intermodal container is counted as two TEUs. 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 12 key ports, which represents approximately 80% of national container unit thruflows. For more details on the wider time series of port data made available for this study, see Appendix III.

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

4.3. 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 effective 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 use of the UNCTAD Trade Analysis Information System (TRAINS) database for effective tariff rates on manufactured goods between the US and its trade partners. 'Manufactures' are an SITC 4 product group predefined on the World Integrated Trade Solution (WITS) platform of the World Bank.

5. Stylized Facts

In this section, I present two stylized facts which 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. While many of these facts have previously been theorized, this study is the first to directly document the responsiveness of the empty container redistribution problem to variation in the US trade balance. Additionally, I provide port-level evidence which suggests that the volume of container traffic at a given port is a strong predictor of whether said port acts as a net inflow or net outflow in terms of its contribution to nationally balanced container flows. I use this third stylized fact to motivate my treatment of the European Custom Area as a single entity, which at only this scale of operations maintains balanced container redistribution comparable to the US.

5.1. 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.*

When combined, Eq.(10) and Eq.(11) imply that a higher export-import ratio of a net importer, the US in this case, implies lower empties as a percentage of total container outflows. As US imports from a net exporter country rises ($X_{ji}/X_{ij} \downarrow$), 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 ($E_{ji} \uparrow$).

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

Given that I do not observe container flows between the US and individual countries, I instead 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),

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

where $\beta < 0$ is my proposed null hypothesis. I use four measures of trade balance skew: the export-import ratio, $\frac{\text{Exports}}{\text{Imports}}$, a net-gross ratio featured in Brancaccio et al. (2020), $\frac{\text{Exports - Imports}}{\text{Total Trade}}$, and their respective opposites of $\frac{\text{Imports}}{\text{Exports}}$ and $\frac{\text{Imports - Exports}}{\text{Total Trade}}$ when addressing inflows of empties. As displayed in Table 1, a relatively smaller US trade deficit is associated a lower in the scale of empty redistribution. This highlights adjustments in the empty repositioning burden that transport operators face, given 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.

I next examine co-movement between empty container flows and opposite-end

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

Clustered (month) 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 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

Clustered (month) 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 net-to-gross trade balance. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

containerized trade flows of the US. As featured in Table 3, empty container flows are highly correlated with opposite-end flows of US trade. My results suggest that a 1 percent rise in US imports is, on average, associated with a 1.45% increase in outflows of empty container units from the US. In sharp contrast, significant unilateral responses are not detected for given roundtrips between the US and the rest of the world. I assume this co-movement is primarily driven by exogenous variation in route-specific unobservables such as preference parameter shifts across consumer bases, wage variation, container unit handling costs and tariff rate adjustments. Examining the robustness of these results in Appendix IV, 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 in trade flows and the opposite-end empty container repositioning problem.

Table 3: Empty Container Elasticity with Respect to Trade Flows

Dependent Variable: Empty Container Flows (TEU)				
	ln(Outbound)		ln(Inbound)	
Model:	(1)	(2)	(3)	(4)
ln(Inbound Trade)	1.450***		-0.0903	
	(0.0917)		(0.2267)	
ln(Outbound Trade)		0.3229		0.8409***
		(0.2489)		(0.2559)
n-obs	120	120	120	120
Within R^2	0.59	0.02	0.002	0.16

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 deflated USD. For example, a one percent increase in 'Inbound Trade' is associated with a 1.45% rise in outbound empty container flows. I use month and year fixed effects to control for influences of the US business cycle and seasonality.

5.2. Balanced Container Flows

Stylized Fact 2. *A positive deviation from the total container units transported from i to j is correlated with a positive deviation from the total 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 redistribution. Upon aggregating across US ports, evidence suggests that national levels of container inflows and outflows appear largely balanced, but only when incorporating contributions made by empty container redistribution. This lends strong support for the balanced container flow constraint, which underpins my partial equilibrium model of empty container redistribution. In Table 4, I regress the total number of inbound container units on the total number of outbound containers 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.

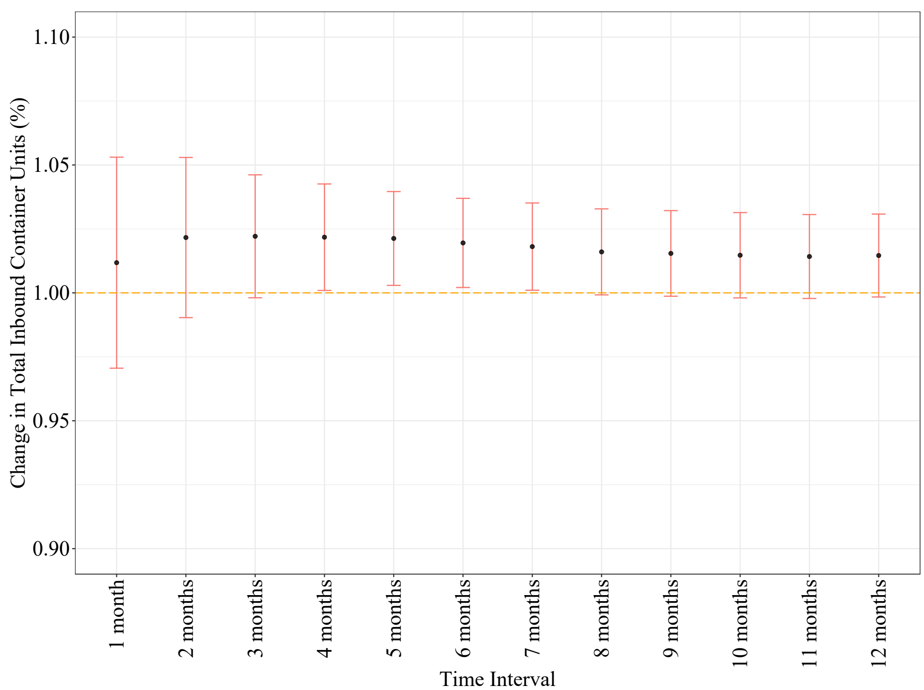
Table 4: Balanced National Container Flows

Dependent Variable: ln(Inbound Container Flows)			
	Total	Loaded	Empty
Model:	(1)	(2)	(3)
ln(Total Outbound)	1.012***		
	(0.0210)		
ln(Loaded Outbound)		-0.0913	
		(0.2841)	
ln(Empty Outbound)			-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. Results are consistent with the inclusion of month and year fixed effects as well as the use of monthly clustering robust standard errors.

Figure 1 suggests that container flows remain balanced across widenining windows of time. As I expand the relevant time interval, through backward sums of loaded & empty container unit flows, noise surrounding these estimations lessens and levels remain approximately balanced a the 1-to-1 percentage point ratio. Although 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.[12]

Figure 1: Balanced National Container Flows by Time Window



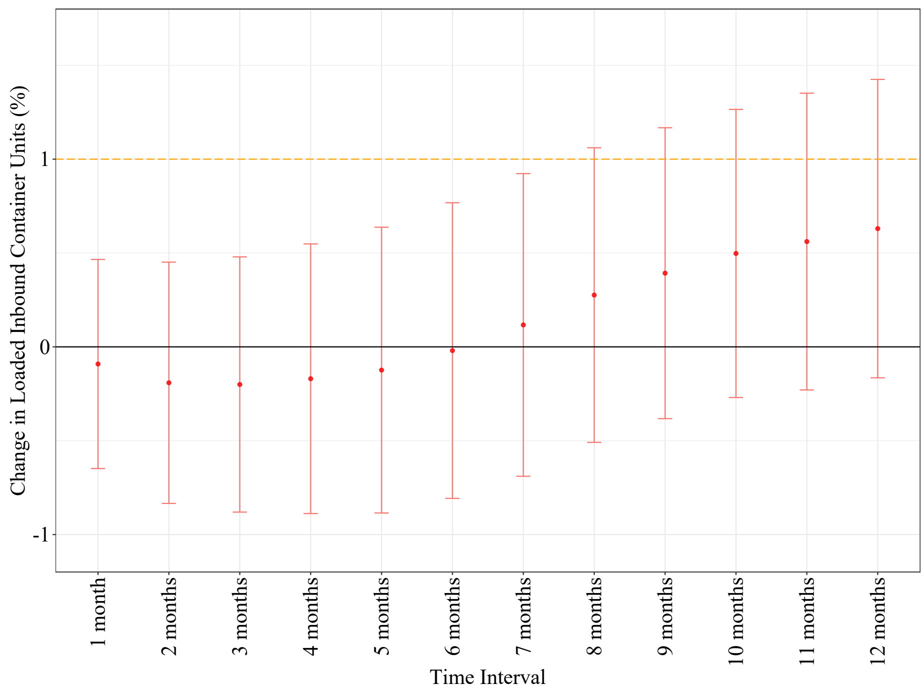
Heteroskedasticity-consistent 'White' standard-errors. Both the dependent variable and regressor are log-transformed. Total inbound containers are summed across a balanced panel of 12 US ports and represent both loaded and empty containers, is regressed on total outbound containers for these same set of ports. Sums are taken across windows of varying lengths of time, ranging from bilateral exchanges within a single month to exchanges across 12 month backward sums.

Container unit measures have largely been focused on loaded traffic flows and often rely on imputed measures available through third-party private entities such as

[12]This is likely a symptom of my sample of ports being based on the largest ports in the US. As I highlight in my next stylised fact, although my container flow data represents over 80% of total container traffic in the US, the smaller ports that I exclude from my sample most likely function as net outflows of container units. With their inclusion, and a full representation of the population of container flows, I hypothesize that my mild deviations from the 1-to-1 balanced container exchange would reduce in size.

S&P Panjiva (Flaaen et al., 2021; Steinbach, 2022; Ardelean et al., 2022). Focusing only on loaded container units – whether reported directly by ports or estimated using Bill of Laden Records from the U.S. Customs and Border Protection (CBP) agency – conceals logistical efforts between the US and the rest of the world. No semblance of balanced container flow patterns are present when excluding empty container repositioning and focusing only on loaded container flows (Figure 2).

Figure 2: Imbalanced National Loaded Container Flows by Time Window



Heteroskedasticity-consistent 'White' standard-errors. Both the dependent variable and regressor are log-transformed. Total inbound containers are summed across a balanced panel of 12 US ports and represent both loaded and empty containers, is regressed on total outbound containers for these same set of ports. Sums are taken across windows of varying lengths of time, ranging from bilateral exchanges within a single month to exchanges across 12 month backward sums.

These findings, when jointly considered, suggest that the system of intermediate transport equipment present in the US achieves a balanced exchange of transport equipment, only when taking into account empty units. In the next subsection, I consider how individual ports contribute to nationwide balanced container flows.

5.3. 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.*

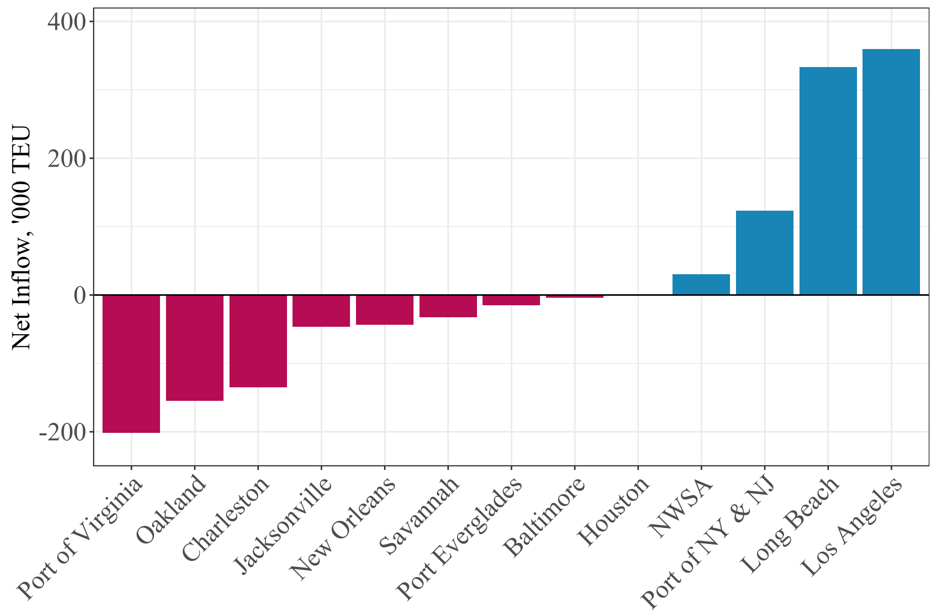
Although total container flows – both loaded and empty containers – are balanced at the national level, patterns in port-level container flows highlight that the largest ports in the US function as net inflows of total containers, while mid-tier sized ports act as net outflows of total container units. This suggests that an 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 Figures 3a and 3b, I display annual net differences in total container flows by port for 2017 along with the geographic dispersion of these key entry and exit points for container equipment.

These statuses are consistent across time. Los Angeles, Long Beach, PANYNJ, and NWSA act as net inflows whereas the remaining set of mid-tier ports are net outflows. As displayed in Figure 4, the total thruflow of loaded and empty containers at a given port is highly predictive 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 between port hubs in order to exploit lower per-unit transport costs (Ganapati et al., 2021). Additionally, one may levy use of a proximity-concentration argument, in which case the best of both worlds would be for imports to arrive at ports positioned closely to 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 larger net inflow ports, where per-unit import prices are likely cheaper (Table 5).

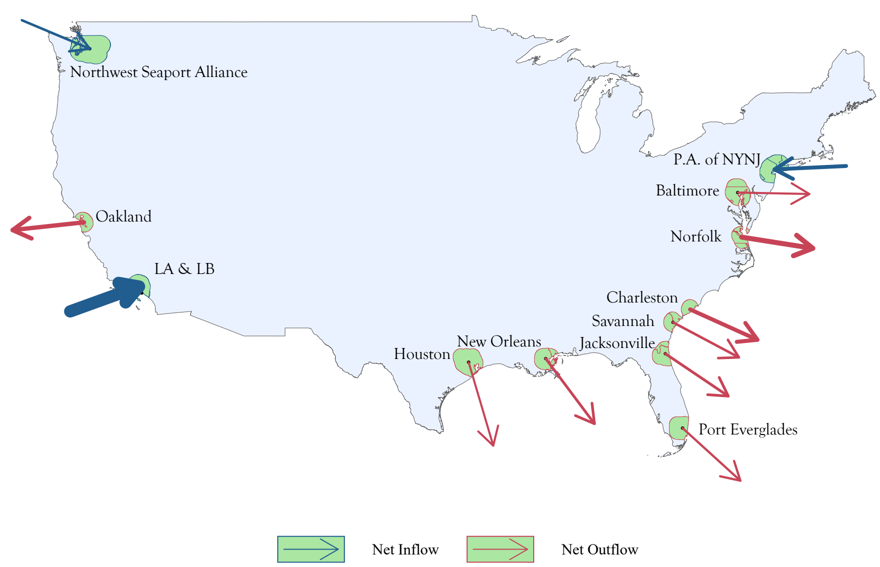
Given that national bilateral container flows are balanced, yet individual ports act as either net inflows or outflows of container units, I suggest that an interdependence across ports which has persisted since at least January 2003. As highlighted in Wong and Fuchs (2022), shipments arriving at major ports see some portion of goods, along with intermodal transport equipment, be transported across the US hinterland.

Figure 3: Port Specialization by Net Inflow Status (2017)

Panel A: Net Inflow of Total Container Units by Port



Panel B: Geographic Dispersion of Net Inflows



While some container units may find their way back to their US port of origin, my findings suggest that many units of equipment departs the US through alternative ports around the country, particularly through mid-tier sized ports. Rather than

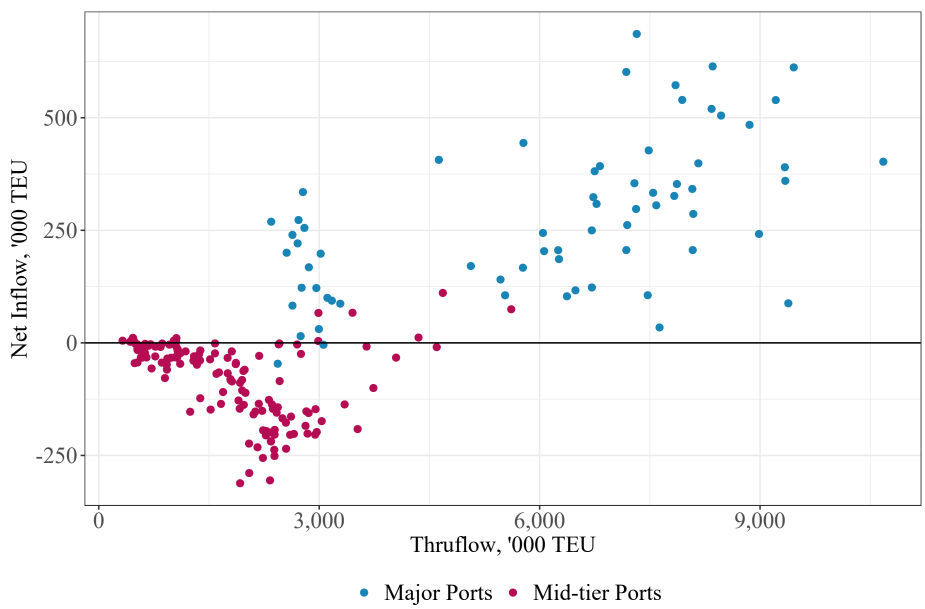
Table 5: Average Containership Gross Tonnage by Port Size

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.

treating each port's trade with the world as an isolated bilateral set of round trip trade routes, this container traffic data exhibits signs of a national-level round trip effect which permeates across ports. Containers are redistributed across US ports and collectively form a balanced container flow system necessary to support round trip containerized trade. This motivates my counterfactual analysis of balanced container flow trade at the country rather than port level.

Figure 4: Port Specialization by Total Container Thruflow (2012-2021)



The intensity of involvement in empty container repositioning also varies widely across ports. In 2021, while larger ports adjacent to net exporter countries – such as Los Angeles or Long Beach – shipped out 70–80% of containers completely empty, the southern ports of Houston (TX), New Orleans (LA) and Jacksonville (FL) have maintained historical averages of 6–22%. As displayed in Table 6, while differences in these shares are longstanding, many of the larger ports and their respective transport operators have been shouldering an increasing burden of the growing US trade deficit and resulting rise in empty container repositioning.

Table 6: Average Empty Share of Container Outflows by Port-Year (%)

Port	2013	2015	2017	2019	2021
Los Angeles, CA	48.69	56.87	57.55	60.61	76.94
Long Beach, CA	46.70	55.52	58.77	61.11	69.05
Port of NY & NJ	44.68	55.34	56.96	60.31	68.89
Savannah, GA	21.91	34.61	32.50	36.00	49.93
Norfolk, VA	15.82	27.93	33.14	37.56	41.18
Charleston, SC	23.19	30.32	30.32	36.61	41.09

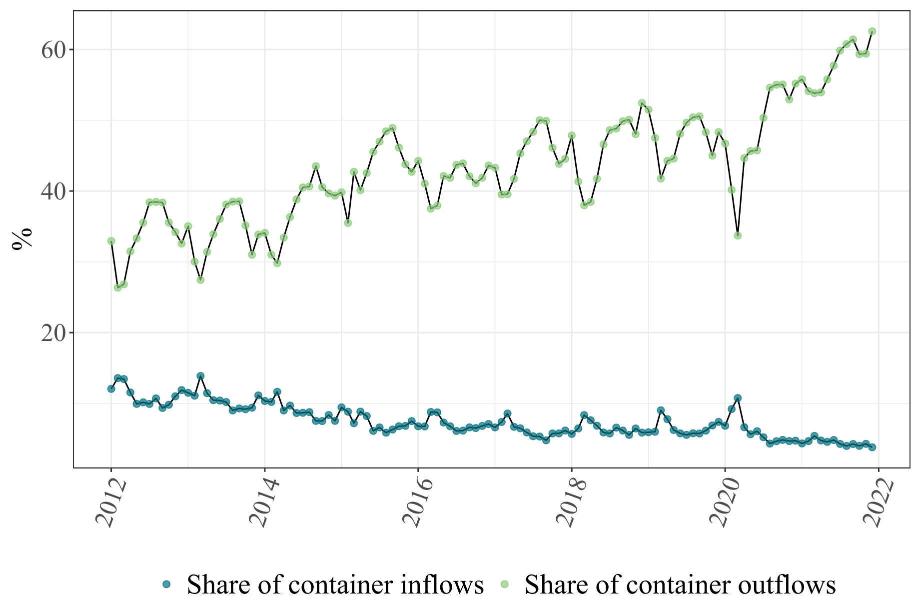
6. Counterfactual

I use the quantitative model featured in Section 3 to consider the policy implications of OSRA22. I first outline a simple two-country baseline scenario of US-RoW (Rest of the World) round trip containerized trade. I then illustrate the flaws associated with this approach, and motivate the estimation of bilateral loaded container flows by US trade partner. By separately representing countries, I include two key features of round trip containerized trade; (i) bilateral flows of empty container units between the US and RoW, and (ii) heterogeneity across trade partners' varying extensive and intensive margins of reliance on empty container outflows from the US. 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 a calibration and estimation of model primitives. Upon establishing this multi-country baseline scenario, I then introduce the counterfactual policy measure – an empty container outflow (ECO) quota, applied through a specific per-unit tax on outgoing empty containers. Accounting for trade partners' varying degrees of reliance on empty containers maintains the same qualitative result of policy backfiring on the import leg of US round trips, but introduces quantitatively larger bilateral adjustments in containerized trade.

6.1. US-RoW Baseline

In a simple two-entity representation of US containerized trade, a single round trip service takes form. Given that I do not observe the origin or destination of port-level container traffic in the US, this is a natural starting point for examining how market intervention would affect containerized trade outcomes. According to the *no excess capacity* constraint featured in Equation (5), empty container flows can only feature on one leg of a round trip route. However, as displayed in Figure 5, the US maintains positive bilateral flows of empty containers with the rest of the world. For example, at the height of the COVID-19 supply chain crisis approximately 63% of outbound containers left the US empty and less than 4% of incoming container units were empty. In order to reconcile this disparity between observed data and a baseline scenario of containerized trade, I use the net difference in empty container flows to represent the scale of the empty container repositioning problem.

Figure 5: Empty Share of Container Movement by Year-Month



In this setting, I establish a baseline scenario of the model using trade and container traffic data specific to average monthly levels reported in 2017.[13] Using a generalized method of moments (GMM) estimator in which a system of trade and

[13]This choice of year avoids any complications that later periods associated with the China-US Trade War and COVID-19 epidemic would introduce.

container flow equations, $\{X_{ij}, X_{ji}, l_{ij}, l_{ji}\}$, featured in Equations (8) and (9), I can represent the endogenous set of moments in the data and exactly identify four unknown model primitives. I reduce the number of unknown exogenous parameters to four 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, represented by ϵ in Eq. (1) and estimated using monthly data by Wong (2022).[14]

While this remedy simplifies a representation of US round trip trade, the use of net empty flows in a single round trip setting also introduces three drawbacks; (i) an under-representation of the scale of the empty repositioning problem, (ii) no distinguishing between net exporter and net importer statuses across US trade partners, and (iii) no acknowledgement of differences in degrees of reliance on the return of empty containers across net exporters. If this first point is left unaddressed, my estimates may under–report both the substitution of transport services from empty repositioning to US exports and the associated contraction of vessel capacity. Secondly, no accounting of trade partners' extensive margin of reliance on empty container inflows from the US leads to policy effects being spread across all participating countries. In order to determine where vessel capacity will retract, these effects must instead be focused on the net exporter subset of trade partners, which rely on these equipment flows. Lastly, the intensive margin of trade partners' reliance on empty container redistribution also needs to be represented in this baseline scenario. Particular net exporters maintain notably more skewed trade imbalances relative to other US trade partners, which deepens the effect of ECO quotas on these round trips in particular. By accommodating for these last two factors, adjustments in vessel capacity and consequential contractions in import levels will be better reflective of particular vulnerability that net exporter trade partners would exhibit.

To incorporate these key features of containerized trade, I prepare a multi-country baseline scenario, which uses observed country-level containerized goods flows by value and estimated volumes of container unit flows to identify a full set of unobserved exogenous parameters via GMM. In the next section, I detail how I estimate loaded container flows by US trade partner.[15]

[14]See Appendix section V for a detailed description of baseline estimation, as well as an assessment of model fit and depiction of the backfiring effect of ECO quotas under a US-RoW setting.

[15]The results of the simple US-RoW baseline setup and counterfactual exercise are detailed in

6.2. Multi-Country Container Flows

To establish a baseline scenario of multiple countries, I require two components; (i) a set of calibrated parameters for each country's round trip with the US, which consists of the real wage and tariff rate for 2017, $\{w_j, w_i, \tau_{ij}, \tau_{ji}\}$, 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 $\{X_{ij}, X_{ji}, l_{ij}, l_{ji}\}$, respectively. Given that I do not observe country-specific flows of loaded container units, I estimate these values using variation in commodity-specific weights of containerized goods exchanged between specific US-country pairs.[16]

6.2.1. Assumptions

Container units used in shipping include a set of operational characteristics which define the maximum weight that each individual unit can carry. Therefore, a positive relationship exists between the number of loaded container units used in transport and the weight of goods shipped to a given country. This fact is well-documented in Ardelean et al. (2022), which finds a consistent synchronization of variation in per-unit freight rates of containerized goods imported to Chile across per-kilogram and per-TEU measures. In support of this evidence, I find that a simple log-log regression of US loaded container inflows on the weight of containerized US imports yields a 1-for-1 co-movement between the two measures.

Individual container units not only feature an explicit weight limit, but also report cubic volume capacity. Both the weight and the cubic volume of a particular set of goods determines how many container units are needed for transport. As Holmes and Singer (2018) demonstrates, the binding constraint for a given container unit is almost always volume, rather than weight. This introduces the possibility that differences in the dimensionality of specific products may 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.

Appendix V.

[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.

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 container using

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

where at US port p, in year-month t, the total number of loaded container units l_{pt} is the sum of containerized weights of country j for commodity k, w_{pjkt}^f, times respective loading factors, β_{jk}. Superscript f indicates the direction that containerized goods and their associated loaded containers are moving from the US perspective. Using these population parameters, the data generating process for a loaded container flows between the US and country j is

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

where combinations of observed w_{pjkt}, and estimated $\hat{\beta}^{fjk}$ allows me to construct fitted values of national container units flows in each direction across J countries. 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 the manner in which cubic volume capacity determines commodity-specific loading factors does not vary across countries. For example, should workers at the port of Mumbai fit three metric tonnes of furniture into a single container unit, I assume that, on average, they use available cubic volume as efficiently as workers loading containers in Rotterdam. Given my assumption of loading factor invariance with respect to the country of origin, my estimation is represented as

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

For a given commodity traded between the US and partner countries, 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 allows me to exploit wider variation in commodity-specific volumes, this restriction may also inadvertently pool within-commodity variation in too aggregated a manner. For example, consider HS item 68 which includes articles of stone, plaster and similar materials. The US may be exporting particularly low quality stone masonry (low loading factor) while more delicate, higher mineral quality articles may originate from Japan (high loading factor). 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 in which for HS-68, as weight increases, the loading factor associated with this shipments lowers.[17]

Lastly, while I do estimate loading factors across 97 HS2 commodity-level goods, I use only the 72 HS2 products featured in the UNCTAD's Trade Analysis Information System (TRAINS) SITC product group of 'manufactures' in establishing a multi-country baseline scenario of the model. This is due to my reliance on manufacturing wage data in the calibration of the model.

6.2.2. Loading Factor Estimates

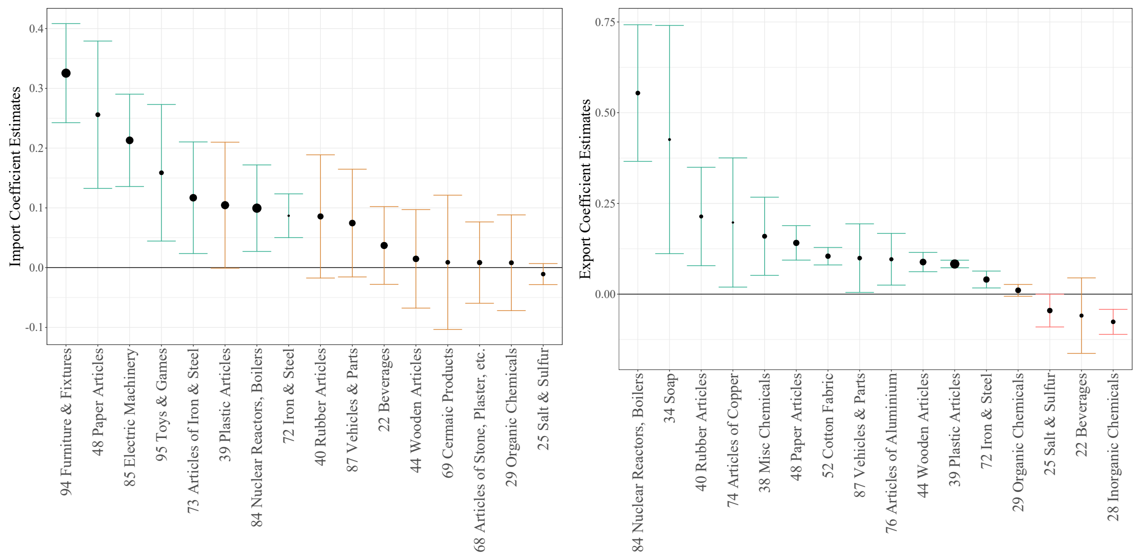
Under these assumptions, I regress Eq.(16) to generate loading factor estimates across a variety of fixed effects combinations, which control for differences in the scale of container flow operations at each port, local industry compositions in each port's surrounding area and potential biases in loading factors attributed to the seasonality of within-commodity variation. To assess the importance of composition differences in commodities by direction at HS2 level, I have estimated both direction-invariant (joint) and f-specific (separate) loading factors.

Across both 'joint' and 'separate' loading factor exercises, I find that port fixed effects are key in minimizing the number of negative coefficients that crop up among the 97 HS2 products included. These negative coefficients would suggest that, all else controlled for, the higher the weight of goods loaded into containers, the lower

[17]To address these potential sources of bias, I have explored country-groupings for a given commodity which potentially limits product differentiation, reducing the influence the differences across quality within a product group may have on the estimation of an appropriate loading factor. These geographic and income-based country groupings for specific commodity weights have been evaluated in Appendix VI and generally contribute little towards improving loading factor estimates.

the number of containers necessary to ship said goods. A rather salient objective therefore is to use the specification which yields the most plausible set of coefficient estimates.

Figure 6: Loading Factor Estimates by Commodity



Clustered (port) standard-errors. Regresses monthly port-level total loaded container inflows (outflows) on a set of commodity-specific weights of containerized US imports (exports), expressed in metric tons. 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 manufactured commodities by value. Observed total container levels and associated containerized weights of goods are observed between Jan-2012 and Dec-2021 and use port & year-month fixed effects. Point sizes vary based on share of associated trade flow.

These estimates are generally significant and positive in value.[18] Combinations of port, year and month fixed effects yield within R^2 values ranging from 0.78-0.97 for imported goods and 0.59-0.98 for goods exports. Furniture, paper articles and electrical machinery are found to be the most demanding commodities on incoming container volumes. For example, a single metric ton of furniture is estimated to take up one third of a container unit whereas a metric ton of iron & steel is estimated to take up only a tenth of a container unit. US exports of nuclear reactors, boilers, soap and rubber articles are estimated to be the most demanding on container volumes whereas plastic articles, iron & steel occupy far less loaded container unit volume.

[18] Appendix VI provides diagnostic tables which highlights that commodities associated with negative loading factors are generally traded in particularly low volumes. Given that each exercise estimates 97 commodity coefficients under varying combinations of fixed effects, it us unsurprising that some false-positive findings of negative coefficients would populate overall results.

Upon predicting port-level container flows & aggregating across US ports, I compare these US estimates to observed national loaded container flows. I find that predicted values using 'separate' loading factors are associated with lower root mean square error values and higher correlation score compared to 'joint' estimates.[19] I therefore focus attention on loading factor estimates specific to the direction in which goods are flowing and generate country–level loaded container flows,

$$\begin{aligned} \text{Container Inflows: } \hat{l}_{j-US,t} &= \sum_{p=1}^{P} \hat{l}_{jpt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \hat{\beta}^{\text{Imp},k} w_{jpkt}, \\ \text{Container Outflows: } \hat{l}_{US-j,t} &= \sum_{p=1}^{P} \hat{l}_{pjt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \hat{\beta}^{\text{Exp},k} w_{pjkt}, \end{aligned} \tag{17}$$

where these bilateral volumes are determined by the product of commodity k's containerized weight at time t and a corresponding time-invariant estimated loading factor, β^{fk}, summed across P ports and K commodities.

6.2.3. Container Flow Estimates

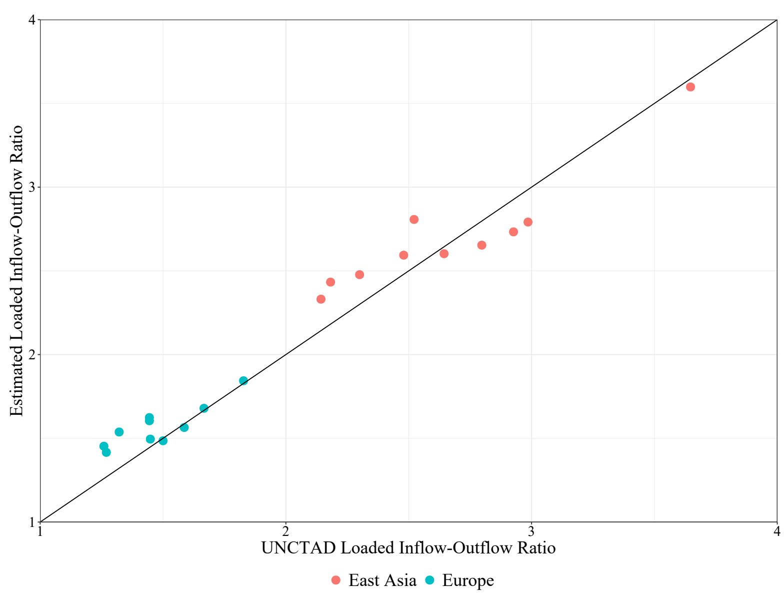
Estimates of loaded container flows are sensitive to the assumptions and methods used in identifying loading factors across commodities. While the 'separate' estimation of loading factors by direction yields far stronger results, the precise set of fixed effects appears open to multiple combinations, so long as port fixed effects are included. 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).

As highlighted previously, product quality likely plays a role in determining the container volume capacity required for the transport of a given metric ton of a specific commodity. To address this concern, I have also estimated loading factor estimates for each commodity specific to groupings of countries by continental boundaries and by income per-capita. Product quality may be correlated across the imports and exports of countries that share close proximity with one another. Similarly, countries of similar wealth levels may trade in goods of a comparable quality levels.

[19] See Table 17 in Appendix VI for further details.

Country-groups' commodity-specific loading factors, each representing a regressor, would introduce a far more substantial extent of sparseness data used for estimation. I address this concern by removing any country-group commodity specific-regressor if less than 40% of its monthly port-level weight flows are reported as positive values. This introduces a trade-off between added precision for key, actively traded commodities across each country-group at the loss of broader commodity representation upon aggregating across port data. Following a series of container flow diagnostics – outlined in Appendix VI – I use port & year fixed effects with no geographic or income-based groupings. These relatively less restricted empirical approaches often introduced greater uncertainty in loading factor estimates without any notable improvement in fits to untargeted UNCTAD measures of two of the US's busiest bilateral lanes of regional loaded container flows. This fit is depicted in Figure 7.

Figure 7: 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.

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] Lastly, given that the model is calibrated on manufacturing wages, I restrict container flow estimates to levels associated with the weight of containerized manufactures travelling between the US and its respective trade partners.[21]

Upon accounting for these product and multi-country constraints, I generate loaded container flow estimates specifically for manufactured goods across the countries featured in Figure 8. This limits my use of multi-country estimated bilateral container flows to represent 70% (50%) of containerized import (export) value.

6.3. Solution Method and Model Calibration

To establish a baseline set of exogenous parameters, I first calibrate a select subset of model primitives and then estimate the remaining set of unknown model primitives 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 the elasticity of substitution measure is represented by ϵ.

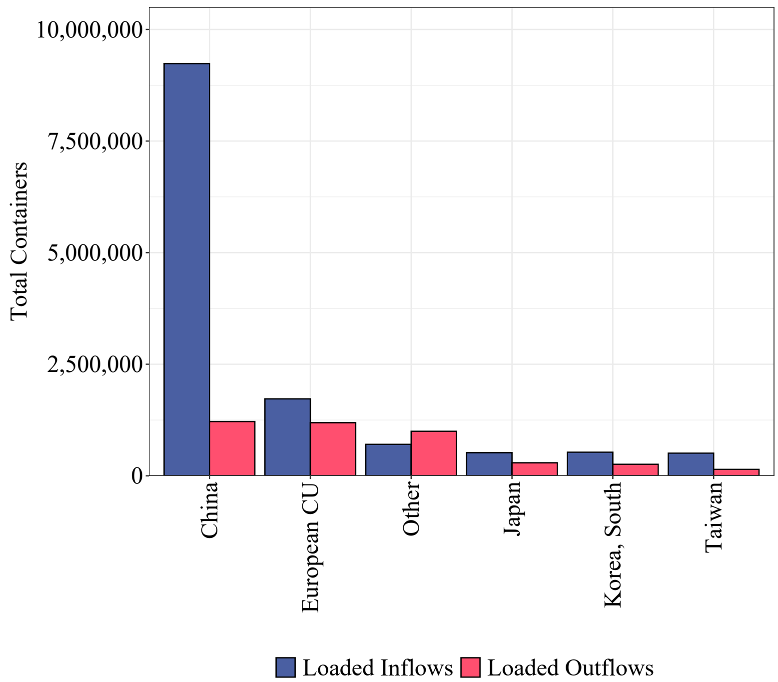
For wages, I use an OECD index of monthly manufacturing income growth rates and the International Labor Organization (ILO) annual measure of monthly manufacturing income levels, which are available for a subset of trade partners. For tariffs, I use the UNCTAD Trade Analysis Information System (TRAINS) database on effective manufactured goods' tariff rates, all of which are reported across US trade partners.[22] 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

[20]See Appendix VII for evidence of balanced container flows only at the Single Market level.

[21]The contributing commodities are those featured in the TRAINS SITC-based product group known as 'Manufactures'. I use the United Nations Statistics Divisions' correspondence tables, HS - SITC/BEC, to convert SITC 4 codes belong to the manufactures product group on TRAINS into a set of relevant HS 2017 codes. https://unstats.un.org/unsd/classifications/Econ Last accessed as of March 17$^{\text{th}}$ 2023.

[22]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.

Figure 8: Estimated Container Flows by Country and Direction



Note: Compared total US container traffic in 2017 across my 12 sampled ports, these disaggregated estimates of manufactured goods flows across the choice subset of trade partners represents 70% (50%) of containerized goods imports (exports) and 65% (43%) of loaded container inflows (outflows). The country group of "other" represents 10 additional lanes of round trip container traffic with the US – consisting of Argentina, Australia, Chile, Columbia, Dominican Rep., Ecuador, Malaysia, the Philippines, Singapore and Turkey.

across major US cities.[23] 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 these calibrated parameters and a vector of 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, $\tilde{\rho} = \left(a_{ij}, a_{ji}, c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\right)$, via GMM.[24] I minimize the object function,

$$R = \text{dist}' \times \bar{W} \times \text{dist}, \tag{18}$$

[23]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 1$^{\text{st}}$, 2022.

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

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.

To assess the performance of this exercise on untargetted features & moments in the data, I provide three means of assessing model fit for this baseline scenario; (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 skew prevailing trade imbalances; (3) using marginal costs of handling loaded, $c_{\underset{ij}{\leftrightarrow}}$, and empty container flows, $r_{\underset{ij}{\leftrightarrow}}$, the implied freight rates suggested by these costs are greater for the portion of US round trips that feature a full set of loaded containers, which is reflective of freight rate asymmetries under imbalanced trade (Hummels et al., 2009).

In order to address the importance of specifying country-specific container flows, I also prepare a US-RoW calibration and estimation of exogenous model primitives using these same inputs. This second baseline scenario, which represents trade through a single round trip, under-represents empty container redisitribution and effectively spreads the reliance on the return of this transport equipment from the US across all trade partners. By introducing both the US-RoW & multi-country baseline scenarios to the same counterfactual change, I quantify the importance of accounting for variation in extensive and intensive margins of dependencies on empty container redistribution from the US.

6.4. Counterfactual Policy Background

In this subsection, I discuss recent changes to liner shipping regulation through the Ocean Shipping Reform Act of 2022 (OSRA22), a portion of which aims to limit empty container redistribution in favor of stimulating greater US exports. To examine the consequences of restricting empty container outflows, I outline a simplified version of this policy in which the policymaker has capped the share of empty container outflows relative to total outflows from the US through a per-unit tax rate.

6.4.1. Pre-policy Conditions

Between October 2021 and November 2022, vulnerabilities in US transport services became notably tangible. A resurgence of economic activity in the US contributed to elevated import demand, which resulted in a widening of the US trade deficit. The associated increase in the asymmetry of bilateral containerized trade volumes coincided with record-high rates of empty container outflows. For example, according container traffic levels provided by the Port Authority of Los Angeles, the percentage of empties featured on container outflows originating from LA increased from a pre-COVID historical average of 50 percent to over 80 percent in the latter half of 2021. As of 2022, for every five containers that entered the US laden with goods, three of these containers leave the US empty.

These signs of elevated empty redistribution are the result of a sudden shift in market conditions. For example, if US demand for Chinese manufactured goods suddenly increased, a greater number of loaded container units would be transported to the US from China. Upon redistributing containers back to China, to service further Chinese export activity, the percentage of empties featured on outbound voyages from the US would rise. Log-jams of vessels and transport equipment also made empty repositioning relatively more appealing. They require less handling due to less time spent transporting goods within a given destination country's hinterland area, are readily usable upon arrival at a destination port and relatively cheaper to transport due to their lower weight. These factors suggest that in certain cases, it may be more profitable for a firm to transport an empty container unit rather than service an additional loaded container unit that cannot be repurposed as quickly.

These opportunity costs and existing differences in import demand between two regions determine the scale of the empty container redistribution problem. Due to the relatively higher opportunity costs of servicing loaded container units and the increased volume of import traffic to the US, a greater percentage of shipping capacity was reassigned to service empty container transport. However, short-run adjustments to a new empty-loaded outflow equilibrium and the increased difficulty for exporters in securing vessel allocated space contributed to a swift bipartisan response from US policymakers.

6.4.2. 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 sought to empower the Federal Maritime Commission (FMC) by introducing legislation that prohibits the 'unreasonable' refusal of vessel capacity from US exports. The stated intention of this bill is to ensure fair trade by supporting good-paying American manufacturing jobs and agricultural exports. Upon passing this proposed legislation on to the Senate, lawmakers were explicit in further emphasizing the intent of this bill.

> *"The rulemaking under paragraph (1)*[25] *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

In February 2022, the Senate passed OSRA22, which maintained this prohibition. 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 first 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. The FMC has

[25] This relates to Section 9 of the proposed bill, Prohibition on Unreasonably Declining Cargo, where transport operators are warned against *"engaging in practices that unreasonably reduce shipper accessibility to equipment necessary for the loading or unloading of cargo"*.

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.[26]

In response, the World Shipping Council (WSC), an association that represents 90% of transport operators, has clarified some of the operational and commercial realities that contribute to empty repositioning. A static export strategy is suggested to not align with the business practices of the industry, which is "volatile with rapidly changing factors that impact space availability on a daily basis." Most notably, the WSC goes on to highlight that "export trades cannot be considered in isolation from import trades". This important facet of containerized shipping acts as the cornerstone of my container redistribution model.

> *Carriers use the same containers, ships, and marine terminals to handle both import and export containers, and vessels operate on continuous loops, not distinct import and export legs disconnected from one another. Additionally, the proposed regulatory language does not address in any way the basic reality that imbalanced trades (as reflected on in the preamble) require the repositioning of equipment, which adds an additional dimension to planning and operating vessel networks. It defies the reality of ocean transportation to ignore these complexities and to treat the export and import legs of a trade as unrelated.*
>
> World Shipping Council response to FMC (2022)

While the FMC continues to deliberate over these key details, I propose an exercise which embodies policymakers' intent of limiting empty redistribution in favor of greater capacity allocation towards US exporters. To capture the potential effects of this unconventional policy approach, I introduce a per-unit tax on empty container outflows to the baseline model, where the tax rate is calibrated to target a capped share of empties as a percentage of total container outflows. I consider a restriction to transport equipment use by the US policymaker, where the expressed goal is to return empty activity back to its historical share of 40% of total container outflows.

[26] No connection is provided in the NPRM between an "export strategy" document requirement and how this establishes a definition of how a transport operator may unreasonably refuse to negotiate or deal with respect to vessel space accommodations. This has led to a second round of public discourse by the FMC and an extension to these deliberations.

To establish this counterfactual scenario, the US policymaker sets a per-unit empty tax rate of γ on the outbound channel of round trip transport, which targets the historical average of empty container share of container gross outflows, $\bar{E}_{ji} = 0.4$. This moderate ECO quota scenario represents a case in which policymakers are content with the prior long run average of the empty container redistribution problem.[27] Using the same tax rate, $\gamma_{\bar{E}_{ji}=0.4}$, on the US-Row version of the baseline scenario, I highlight the benefits of accounting for heterogeneous dependencies on empty container redistribution from the US.

6.5. Main Results

As displayed in column 3 of Table 7, 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. 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 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

[27] 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.

Table 7: Disaggregated Counterfactual Outcomes

Measures (2017)	US-RoW	Multi-Country
US Imports	-17.91	-17.74
US Exports	26.54	31.13
Loaded US Inflows	-18.71	-19.46
Loaded US Outflows	28.04	35.46
US Import Price	0.81	1.72
US Export Price	-1.50	-4.34
Total Value	-9.53	-8.53
Total Volume	-5.89	-4.39
Vessel Capacity (TEU)	-18.71	-18.56
US Empty Outflow Share	-34.98	-37.43
US Import-Export Ratio	-35.12	-37.26

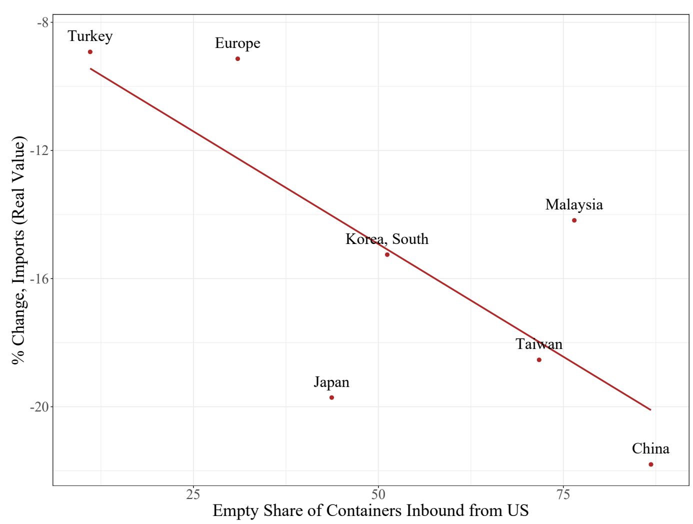
Note: These results reflect percentage changes from their respective baseline scenarios of the partial equilibrium model and are based on estimates of loaded container flows and observed levels of associated trade in containerized manufactured goods.

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.

In column 2 of Table 7, I list the counterfactual results of this setting, had only aggregated flows of container units been considered. This US-RoW setting ignores which trade partners are reliant on empty container returns and represents only the net flow of empty container units. Upon calibrating a baseline model in this fashion and introducing an identical empty container tax, I find that the overall magnitude of shocks to various trade outcomes is generally lower. Furthermore, the loss in terms of lower trade activity is overestimated when approaching this model from a US-RoW perspective. Therefore, when considering such policy, I would strongly emphasize representing the true scale of the empty container repositioning problem and targeting policy effects correctly across multiple countries, rather than relying on aggregated moments in the data.

Across the subset of net exporters which engage in containerized trade with the US, the pre-existing scale of the empty container repositioning problem acts as a strong predictor of this policy's. Measuring this scale as US outflows of empties to country i as a percentage of total US container outflows to country i, I find that countries particularly reliant on empty repositioning yielded the highest declines in imports. As highlighted in Figure 9, 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. Transport operators servicing these routes respond by introducing larger contractions in vessel capacity, which in turn lowers the value and volume of imports shipped from East Asia to the US. The greater each country's intensive margin of reliance on empty containers, represented by the empty share term, the greater the decline in import levels.

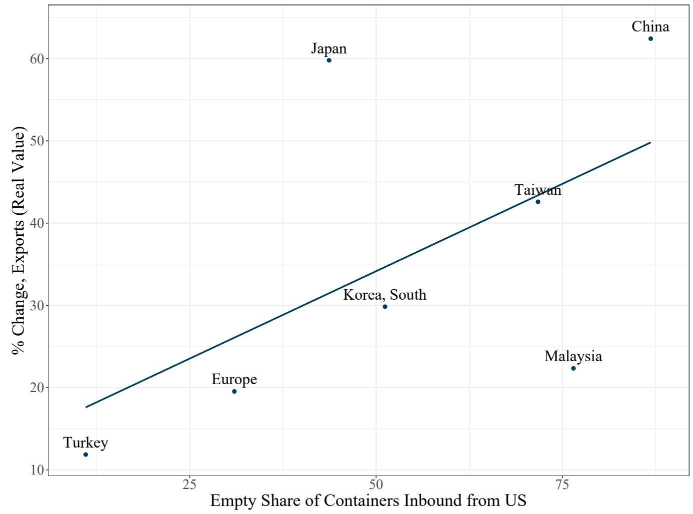
Figure 9: US Import Value by Net Exporter (2017)



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.

Given that the repositioning of empties has become more expensive, the underlying costs of loaded container services are relatively more appealing. This is reflected by a decline in the US-net exporter freight rate and a substitution into increased US export activity across net exporter round trip trade routes. Countries such as China and Japan yield greater changes due to their particularly significant reliance on empty containers and greater declines in export prices (Figure 10).

Figure 10: US Export Value by Net Exporter (2017)

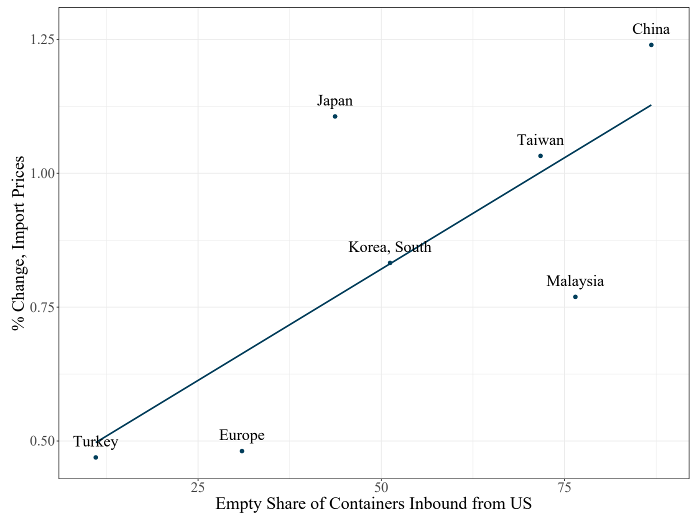


Note: The real value of exports is used, deflated by US CPI for urban areas, less food and energy. The empty share represents $100 * \frac{\text{US-Country Empty Outflows}}{\text{Total US-Country Outflows}}$, and reflects pre-policy shares of total container outflows.

Lastly, the inflationary pressure generated by a tax on empty container units appears to have particularly pronounced effects on endogenous import prices across the net exporters that exhibit a greater reliance on empties. As displayed in Figure 11, Turkey and Europe yield relatively low pass-through of this new tax burden on prevailing market prices. However, East Asia yet again yields evidence of greater exposure to this form of protectionism, in which percentage point increases in price levels are almost threefold larger.

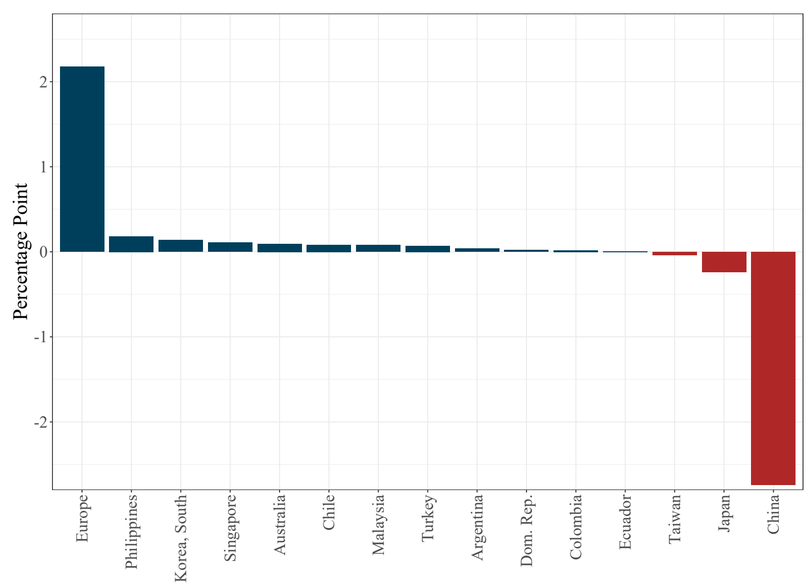
The sizable loss in transport equipment accessibility and the acuteness of this decline on routes with a particularly high dependencies on empty repositioning leads to noteworthy changes in country shares of the US import market. As displayed in Figure 12, in some cases net exporters gain market shares despite being reliant on empty container repositioning. China, which receives approximate 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 Custom's Area developing a larger share of overall US imports, despite being negatively affected by an ECO quota.

Figure 11: US Import Price Inflation by Net Exporter (2017)



Note: Real prices are reflective of the average value of containerized goods per loaded TEU. Deflated using US CPI for urban areas, less food and energy. The empty share represents $100 * \frac{\text{US-Country Empty Outflows}}{\text{Total US-Country Outflows}}$.

Figure 12: 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.

7. Conclusion

This paper provides a quantitative approach towards understanding the novelties of containerized trade and its reliance on the repositioning of physical transport equipment. The first contribution of this study identifies how variation in the availability of transport equipment may feed into trade outcomes on the opposite leg of a given round trip, and enriches means of incorporating endogenous transport costs. In this particular case, I internalize the cost of repositioning container units to associated transport operators and highlight how variation in such costs may result in adjustments to the available transport capacity devoted to a particular origin-destination pair. Using novel container traffic data provided by the largest ports in the US, representative of 80% of gross container unit traffic, I directly connect theory and empirics. Through this connection, I document a round trip effect taking place in which adjustments in the prevailing trade balance of the US, through larger trade deficits, enlarges the scale of the empty container repositioning problem. Through supportive evidence, I argue that it is opposite-leg trade outcomes that drives variation in the empty container repositioning problem of the US.

I also contribute theoretically to the literatures of international trade and transport economics through my partial equilibrium model of container repositioning. This model that 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 modelling imbalance round trip trade in which the lower volume leg of a given route yields a freight rate of zero. Additionally, this challenge is not unique to maritime commerce and can be considered applicable across multiple modes of transport. In future work, it would be of interest to understand how this phenomenon interacts with recent developments in market concentration across the global fleet of transport operators. For example, does a greater extent of coordination through cooperative shipping alliances across the global fleet limit container shortages?

Lastly, I quantitatively evaluate how interfering in the use of this transport technology can affect 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. I highlight how a modern and unconventional form of protectionism may backfire. This specific form of 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 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."

These considerations are important to consider, not only in maritime shipping, but across trucking, rail and airline services. Each of these forms of round trip service accommodate differences in trade volume. As I highlight, particularly asymmetric round trip volumes are the most subject to malaise effects, given the introduction of empty container repositioning regulation. Should we wish to fully embrace trade flows, irrespective of differences in bilateral flows, this requires particularly low costs of handling empty containers. According to these comparative statics, developments in foldable container technology would dramatically cut required dock space for storage and further expand global trade opportunities.

Going forward, I believe this study adds emphasis toward more granular data on port traffic and container shipping details. I welcome the data provision requirements introduced through OSRA22, which enables the Federal Maritime Commission to publish a quarterly report detailing the total import and export tonnage and the total loaded and empty 20-foot equivalent units per vessel operated by ocean common carriers. Upcoming container tracking technology would be of great interest and enable studies such as this paper to directly connect port container traffic through the US hinterland. As my estimation country-specific container flows may indicate, further studies of maritime transport would also be enhanced by a greater knowledge of container origins, routes travelled upon and ultimate destinations. These improvements in data availability would enhance the identification of key transport bottlenecks, allow for the accounting of transshipping activity and better our understanding of countries' joint dependency on efficient transport equipment usage.

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)

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

I adjust this specification to a more general form which sets all container input prices equal to a route specific cost term $\{c_{ij}, c_{ji}, r_{\overset{\leftrightarrow}{ij}}\} = c_{\overset{\leftrightarrow}{ij}}$. 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.

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

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. 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.

Upon acknowledging these underlying differences in handling costs between empty and loaded containers through heterogeneous input prices, within route, the general equilibrium model is capable of generating positive freight rates for both sides of an imbalanced round trip trade on $\overleftrightarrow{ij}$. I use heterogeneous input prices to generate empty container flows in conjunction with positive bilateral tariff rates.

II. Balanced Trade Scenario

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

$$\begin{aligned}
\left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}(w_i\tau_{ij}+T_{ij})^{-\epsilon} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\right)^{-\epsilon}\left(w_j\tau_{ji}c_{\overleftrightarrow{ij}}+c_{\overleftrightarrow{ij}}-T_{ij}\right)^{-\epsilon} \\
\frac{1}{a_{ij}}(w_i\tau_{ij}+T_{ij}) &= \frac{1}{a_{ji}}(w_j\tau_{ji}+2c_{\overleftrightarrow{ij}}-T_{ij}) \\
\left(\frac{1}{a_{ij}+a_{ji}}\right)T_{ij} &= \frac{1}{a_{ji}}\left(2c_{\overleftrightarrow{ij}}\right)-\frac{1}{a_{ij}}(w_i\tau_{ij})+\frac{1}{a_{ji}}(w_j\tau_{ji}) \\
(a_{ij}+a_{ji})\,T_{ij} &= a_{ij}\left(2c_{\overleftrightarrow{ij}}\right)-a_{ji}(w_i\tau_{ij})+a_{ij}(w_j\tau_{ji}) \\
T^*_{ij} &= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\overleftrightarrow{ij}})-\frac{1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij})+\frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \quad (19)
\end{aligned}$$

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

$$
\begin{aligned}
p^*_{ij} &= w_i\tau_{ij} + T^*_{ij} \\
&= w_i\tau_{ij} + \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\overset{\leftrightarrow}{ij}}) - \frac{1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij}) + \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \\
&= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\overset{\leftrightarrow}{ij}}) + \frac{1+\frac{a_{ij}}{a_{ji}}-1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij}) + \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji}) \\
p^*_{ij} &= \frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\overset{\leftrightarrow}{ij}} + w_i\tau_{ij} + w_j\tau_{ji}\right) \qquad (20)
\end{aligned}
$$

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

$$
\begin{aligned}
l^*_{ij} &= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(w_i\tau_{ij} + T^*_{ij}\right)^{-\epsilon} \\
&= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(w_i\tau_{ij} + \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(2c_{\overset{\leftrightarrow}{ij}}) - \frac{1}{1+\frac{a_{ij}}{a_{ji}}}(w_i\tau_{ij}) + \frac{1}{1+\frac{a_{ji}}{a_{ij}}}(w_j\tau_{ji})\right)^{-\epsilon} \\
&= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(\frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\overset{\leftrightarrow}{ij}} + w_i\tau_{ij} + w_j\tau_{ji}\right)\right)^{-\epsilon} \qquad (21)
\end{aligned}
$$

The equilibrium value of trade is simply price times quantity:

$$
\begin{aligned}
X^*_{ij} &= l^*_{ij}p^*_{ij} \\
&= \left(\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(\frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\overset{\leftrightarrow}{ij}} + w_i\tau_{ij} + w_j\tau_{ji}\right)\right)^{1-\epsilon} \qquad (22)
\end{aligned}
$$

III. Container Traffic Sample

In Table 8, 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.

Table 8: 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 of the Appendix, I address alternative specifications which mirror those proposed in the main body of this study. Figure 9 depicts the co-movement between empty container units and trade flows travelling in the same direction for a given year-month, between the US and RoW. I find no distinct relationship, suggesting that only opposite leg variation in trade flows stimulate systematic adjustments to empty container repositioning. This opposite-leg relationship between trade flows and corresponding empty container unit adjustments is reflected in Table 3.

Tables 10 & 11 and Figure 13 mirror national regressions featured in the main body of the paper. Generally these findings are weaker, which is partly due to ports

Table 9: 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.

not individually maintaining balanced container flows. Only in conjunction with other ports does the US maintain nationally balanced container flows and response relationships between prevailing trade flows and opposite-end empty container movements.

Table 10: (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

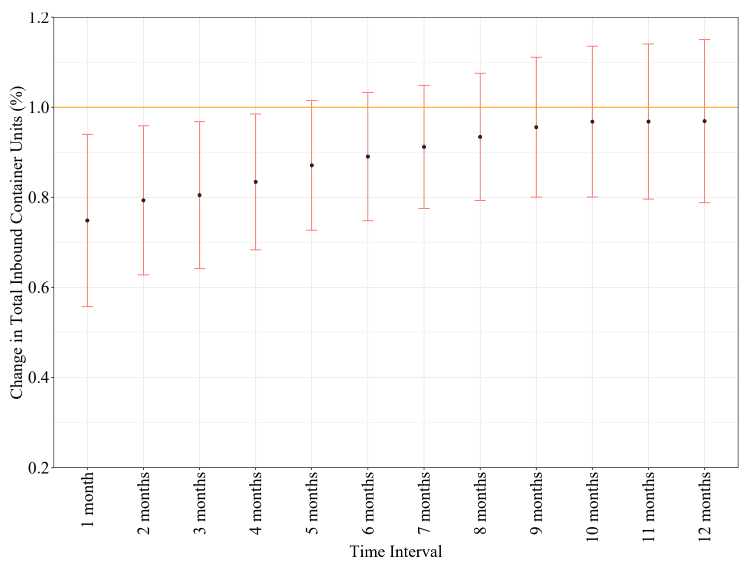
Clustered (port) standard-errors in parentheses. Codes: ***: 0.01, **: 0.05, *: 0.1. Examines variation empty containers as a share of total container outflows, given variation in the skewedness of the trade balance. I use month and year fixed effects to control for influences of the US business cycle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

Table 11: (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.

Figure 13: Balanced Port Container Flows



Clustered (port) standard-errors in parentheses. Both the dependent variable and regressor are log-transformed. Total inbound containers are reported across a balanced panel of 12 US ports and represent both loaded and empty containers, is regressed on total outbound containers for these same set of ports. Sums are taken across windows of varying lengths of time, ranging from bilateral exchanges within a single month to exchanges across 12 month backward sums. All models include port-year, port-month and year-month fixed effects.

V. US-RoW Model Results

Solution Method and Model Calibration

To establish a baseline set of exogenous parameters, I first calibrate a select subset of exogenous parameters and then estimate the remaining set of unknown model primitives. For a given ij round trip containerized shipping route, the set of unknown exogenous parameters ρ is equal to $\left(a_{ij}, a_{ji}, w_i, w_j, \tau_{ij}, \tau_{ji}, c_{\overleftrightarrow{ij}}, r_{\overleftrightarrow{ij}}\right)$ and the elasticity of substitution measure is represented by ϵ.

The wage-tariff product $w_i \tau_{ij}$ is a component of tradeable good prices featured in Section 3. I use an OECD index of monthly manufacturing income growth rates, the International Labor Organization (ILO) annual measure of monthly manufacturing income levels, and UNCTAD Trade Analysis Information System (TRAINS) database on effective manufacturing goods' tariff rates, all of which are reported across a subset of key US trade partners. [28] I deflate these measures 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.[29] I focus primarily on statistics associated with manufacturing due to its high share of overall containerized goods flows. For more of an elaboration on the calibration of $w_i \tau_{ij}$, see Appendix IV. Lastly, I use an estimate of price elasticity of demand provided by Wong (2022) and specific to containerized trade, where $\hat{\epsilon} = 20.95$ is assumed to be common across individual trade routes.

Given calibrated estimates of real wage levels, tariff rates and the price elasticity of demand, the remaining four unknown parameters, $\tilde{\rho} = \left(a_{ij}, a_{ji}, c_{\overleftrightarrow{ij}}, r_{\overleftrightarrow{ij}}\right)$ can be identified via a Generalized Method of Moments (GMM) approach. I minimize the object function,

$$R = \text{dist}' \times \bar{W} \times \text{dist}, \tag{23}$$

where dist represents the log difference in vectors of observed and model-guess trade

[28] 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

[29] 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 1, 2022.

outcomes, $\log(Y^{\text{data}}) - \log(Y^G)$ and $\bar{W}$ is a weight matrix that assists in speeding the identification of $\tilde{\rho}$.[30] I use observables from 2017 to estimate these parameters of underlying long-run primitives of containerized trade. This decision allows me to avoid any complications or concerns that the use of data from the proceeding China-US trade war, COVID-19 pandemic and port congestion saga could introduce.

Table 12: Key Parameters, 2017

a_{ij}	a_{ji}	$c_{\overset{\leftrightarrow}{ij}}$	$r_{\overset{\leftrightarrow}{ij}}$
65,972	32,978	20,770	8,929

I provide four means of assessing model fit for this baseline scenario of the counterfactual exercise; (1) referring to Table 12, the difference in preference parameters attributes greater demand towards US imports relative to US exports, which is reflective of the existing import-export ratio for 2017; (2) using marginal costs of handling loaded, ($c_{\overset{\leftrightarrow}{ij}}$), and empty container flows, $r_{\overset{\leftrightarrow}{ij}}$, the implied freight rates suggested these costs are greater for the portion of US round trips that feature a full set of loaded containers, which is reflective of freight rate asymmetries under imbalanced trade (Hummels et al., 2009); (3) the empty container redistribution share of container fleet managing costs is 11%, which places it relatively close to 15% reported by Notteboom et al. (2022); (4) baseline scenario empty container outflows each year of 2012 to 2021 are 99% correlated with untargeted observed empty outflows.

Counterfactual Scenarios

I consider two cases of restrictions to transport equipment use by the US policymaker, where the expressed goal is to discourage empty container redistribution in favor of stimulating US exports. In each case, restrictions are implemented through a per-unit tax on empty outflows from the US, which increases marginal costs to $(1+\gamma)\, r_{\overset{\leftrightarrow}{ij}}$. The tax rate, γ, is configured to target a specific ECO quota, represented by $\bar{E}_{ji}$, the maximum share of empties as a percentage of total container outflows. I establish two scenarios which demonstrate how sensitive trade outcomes are to variation in the availability of empty container equipment.

[30] For each US trade partner, a vector of four observables are used $Y^{\text{data}} = (l_{ij}, l_{ji}, X_{ij}, X_{ji})$. From left to right, these variables represent loaded container inflows, loaded container outflows, containerized imports, and containerized exports between the US and that respective trade partner.

1. In the case of a moderate policy response, the US policymaker set a tax on empty input costs of γ^{mod}, which targets the historical average of empty container share of container net outflows, $\bar{E}_{ji} = 0.3$. This scenario represents a case in which policymakers are content with the former status quo of the empty container redistribution problem.

2. In this second scenario, I consider a case in which policymakers set a sufficiently high tax of γ^{ext}, which eliminates empty container outflows from the US by establishing an extreme quota of $\bar{E}_{ji} = 0$. This second case allows me to quantify the contribution the empty container redistribution problem to variety of US trade outcome variables.

In the next section I outline how this unconventional form of trade policy backfires in each of these exercises, relative to the baseline scenario of $\gamma = 0$, via the round trip effect.

Results

The targeting of ECO quotas, achieved through per-unit taxes on empty container unit outflows, reduces the scale of the empty redistribution problem and lowers overall round trip service capacity. Reduced transport capacity yields debilitating effects on the opposite leg of a given $\overset{\leftrightarrow}{ij}$ trade route.

As displayed in column 2 of Table 13, a moderate ECO quota contributes to a one-third decline in the volume empty container redistribution problem. If focusing only on this outbound leg of US round trip transport, the changes appear positive from the policymaker perspective. Relative to the baseline scenario, US containerized exports increase by 12.5% in real value as transport operators substitute away from relocating empties and towards servicing additional loaded container units. The US containerized trade deficit, represented by the import-export ratio, also declines by 21.5%. While the combination of these two findings would likely signal a positive outlook for similar policies of transport equipment restrictions, this outflow perspective alone would ignore malaise effects observed on the opposite leg of a given round trip.

On the opposite leg, US trade partners now face a freight rate which includes a higher cost of redistributing empties back for round trip transport service provisions. The equilibrium quantity of container units declines, which represents a reduction in the transport capacity for containerized transport services for the US. As a result of government intervention on export routes, the opposite leg of trade exhibits the round trip effect where available capacity declines by 6.1% and import prices rise by 0.3%. When combined, this contributes to a 5.8% reduction in the real value of US imports. The gross values of total imports and exports combined declines by 2% relative to the baseline scenario, suggesting an overall reduction in trade activity.

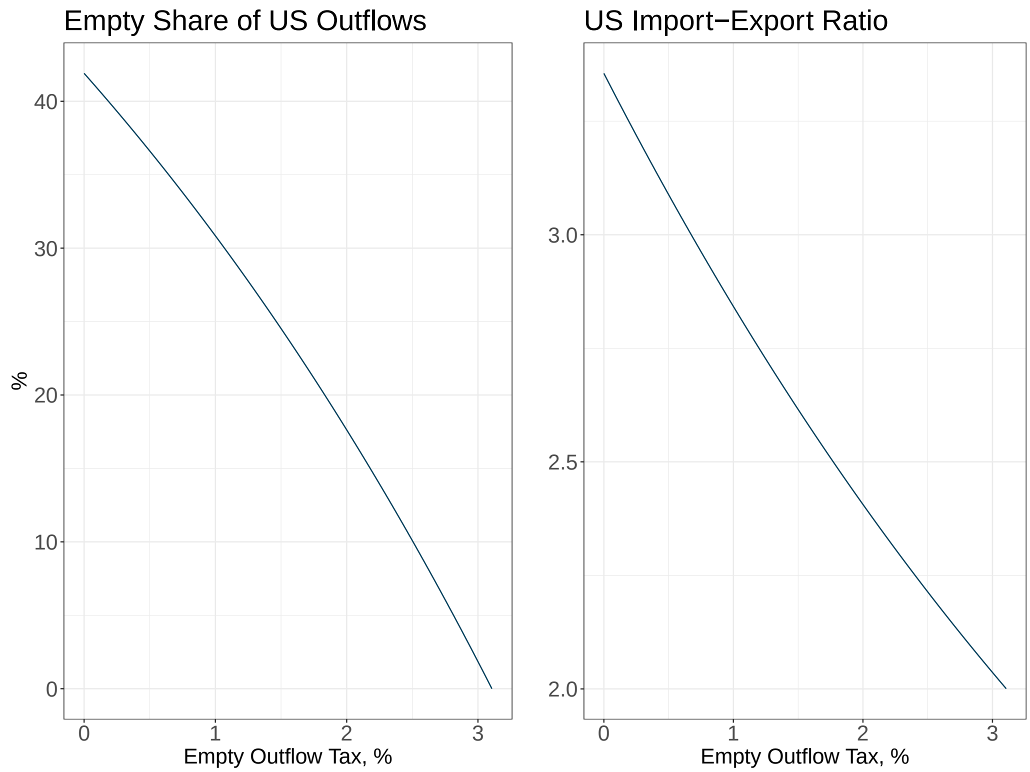
Table 13: National Counterfactual Outcomes

US Measures (2017)	$\%\Delta Y_{\bar{E_{ji}}=0.3}$	$\%\Delta Y_{\bar{E_{ji}}=0}$
Import Value with RoW	-5.82%	-15.96%
Export Value with RoW	12.46%	40.96%
Loaded Container Inflows from RoW	-6.11%	-16.68%
Loaded Container Outflows to RoW	13.13%	43.41%
Import-Export Ratio	-21.48%	-40.38%
Empty Share of US container outflows	-16.26%	-100.00%
Empty Container Outflows from US	-32.78%	-100.00%

In the extreme quota case $\left(\bar{E}_{ji} = 0\right)$, the backfiring of this policy has far more dramatic effects on bilateral trade flows. The value of imports fall by 16% while export activity grows by 41%. The US trade deficit narrows, reflected by a 40 per cent drop in the import-export ratio. Despite empty containers no longer featuring on round trip routes, the US still maintains net importer status with imports being 2 fold that of exports (see Figure 15). The gross value of trade flows declines by 3% under these circumstances and the ocean-borne capacity of round trip trade servicing the US declines by 16.7%.

These results highlight that if policymakers focus only on the immediate goal of stimulating exports, without acknowledging the market response this would have on round trip trade patterns, they may underestimate the costs these policies are likely to have for the general public. Specifically, lower levels of imports at more expensive rates would need to also be taken into account. The combination of the exports increases and import declines, due to the round trip effect, worsens a country's overall level of trade participation, which limits the gains to trade.

Figure 14: Counterfactual Outcomes by Empty Outflow Tax, 2017



Note: The required rates of tax for moderate and extreme quota outcomes are 1.1 and 3.1 percent rates, respectively. The empty share of US container outflows declines concavely with respect to an empties tax. The Import-Export ratio, although more than 3.5 in the baseline scenario, declines in moderate and extreme counterfactual cases to ratios of 2.8 and 2, respectively.

VI. Loading Factor Estimates & Container Flow Diagnostics

While allowing commodity-specific loading factors to vary by directional flow is one decision worth considering, I have also included aggregations of particularly low volume commodity types to observe how costly a lowering of regressors is to the accuracy of my methodology. As displayed in Table 17, I compare the national container predicted by these varying specifications relative to a time series of observed loadedc container flows, both items being aggregated to total container inflows (In) and outflows (Out), respectively. I find that 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 for in the notes section of the table. For the purposes of this paper, I use the 'Full – Separately' approach to generate country-specific container flows.

Table 14: Jointly Estimated Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
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	port+year
0.077	0.105	23	59.150	81.216	31.94	port+mon
0.126	0.173	21	61.769	84.812	29.17	year+mon
0.071	0.098	18	63.910	87.751	25.00	port-year
0.127	0.174	22	59.969	82.340	30.56	year-mon
0.078	0.107	23	60.485	83.049	31.94	port-mon
0.067	0.091	20	61.062	83.842	27.78	port-year + mon
0.074	0.102	21	60.600	83.207	29.17	year-mon + port
0.076	0.105	23	58.985	80.989	31.94	port-mon + year
0.057	0.078	16	64.163	88.099	22.22	portˆyearˆmon
0.075	0.103	23	60.330	82.836	31.94	port+year+mon

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.

Table 15: Import-Specific Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
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	port+year
0.120	0.139	3	86.318	99.546	4.17	port+mon
0.152	0.175	19	70.990	81.869	26.39	year+mon
0.114	0.131	2	86.139	99.340	2.78	port-year
0.153	0.176	20	70.976	81.854	27.78	year-mon
0.119	0.137	4	83.897	96.754	5.56	port-mon
0.113	0.131	2	86.477	99.730	2.78	port-year + mon
0.115	0.132	2	86.410	99.653	2.78	year-mon + port
0.114	0.131	4	82.490	95.132	5.56	port-mon + year
0.115	0.133	2	86.410	99.653	2.78	port+year+mon

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.

Alternative specifications for regressors have been evaluated with respect to 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. In the following section, I detail the performance of these measures, which generally appear to under–perform relative to the directional loading factors used.

Geographic Loading Factors: Loading factors are estimated both jointly – pooling import and export data together – and separately, where commodity-specific loading factors vary based on whether they are an import or export. Groups include Asia, Australia & Oceania, Europe, the Middle East & Africa, and Southern & Central America.

Table 16: Export-Specific Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
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	port+year
0.069	0.129	4	48.449	91.142	5.56	port+mon
0.064	0.121	13	48.464	91.169	18.06	year+mon
0.062	0.117	0	53.158	100.000	0.00	port-year
0.065	0.123	10	48.685	91.584	13.89	year-mon
0.068	0.129	4	48.449	91.142	5.56	port-mon
0.059	0.111	0	53.158	100.000	0.00	port-year + mon
0.070	0.133	5	48.442	91.127	6.94	year-mon + port
0.071	0.134	5	48.423	91.093	6.94	port-mon + year
0.071	0.133	4	48.449	91.142	5.56	port+year+mon

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.

Table 17: 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: The method list indicates which set of commodities were used as regressors in the estimation of commodity-specific loading factors. '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.

Table 18: Jointly Estimated Geographic Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.139	0.192	31	65.051	89.550	11.31	none
0.090	0.124	31	65.818	90.606	11.31	port
0.111	0.153	36	61.362	84.472	13.14	year
0.112	0.154	36	62.023	85.382	13.14	mon
0.088	0.122	30	66.755	91.896	10.95	port+year
0.088	0.121	32	64.542	88.850	11.68	port+mon
0.110	0.152	36	62.137	85.538	13.14	year+mon
0.082	0.113	29	67.714	93.216	10.58	port-year
0.110	0.151	38	62.013	85.368	13.87	year-mon
0.091	0.126	31	66.112	91.010	11.31	port-mon
0.078	0.108	26	68.834	94.757	9.49	port-year + mon
0.085	0.117	28	67.002	92.236	10.22	year-mon + port
0.090	0.123	30	65.002	89.482	10.95	port-mon + year
0.065	0.090	29	65.783	90.558	10.58	portˆyearˆmon
0.086	0.118	28	65.829	90.620	10.22	port+year+mon

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.

Income Loading Factors: Loading factors are estimated both jointly – pooling import and export data together – and separately, where commodity-specific loading factors vary based on whether they are an import or export. Groups include quartiles of countries, divided by World Bank measures of GDP per capita.

Table 19: Import-Specific Geographic Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.175	0.203	21	75.554	87.264	8.4	none
0.119	0.137	7	86.090	99.433	2.8	port
0.123	0.142	21	74.528	86.079	8.4	year
0.120	0.138	22	77.493	89.503	8.8	mon
0.115	0.133	7	86.251	99.619	2.8	port+year
0.120	0.139	7	86.004	99.334	2.8	port+mon
0.120	0.138	24	77.213	89.180	9.6	year+mon
0.111	0.129	6	84.942	98.107	2.4	port-year
0.124	0.143	28	75.290	86.959	11.2	year-mon
0.119	0.137	9	86.131	99.480	3.6	port-mon
0.111	0.129	7	84.820	97.966	2.8	port-year + mon
0.117	0.135	5	86.157	99.510	2.0	year-mon + port
0.116	0.133	8	86.162	99.516	3.2	port-mon + year
0.116	0.134	6	86.177	99.533	2.4	port+year+mon

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.

Container Flow Diagnostics

As highlighted in Tables 24 and 25, 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 Asian, geographic country groupings perform similarly to loading factors which vary only by commodity. For Europe, the standard approach of commodity-specific loading factors with no interference in the loading factor estimations delivers the most accurate results. Considering both regions jointly, I proceed with using no arbitrary country groupings nor any interference with estimated loading factors.

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

Table 20: Export-Specific Geographic Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.083	0.157	11	52.322	98.630	4.10	none
0.072	0.136	11	52.446	98.864	4.10	port
0.071	0.133	19	51.811	97.666	7.09	year
0.073	0.137	19	51.135	96.393	7.09	mon
0.071	0.134	9	52.723	99.385	3.36	port+year
0.072	0.135	9	52.572	99.101	3.36	port+mon
0.072	0.136	19	51.811	97.666	7.09	year+mon
0.060	0.114	7	53.004	99.914	2.61	port-year
0.072	0.136	17	51.966	97.958	6.34	year-mon
0.076	0.143	9	52.711	99.362	3.36	port-mon
0.058	0.110	7	53.004	99.914	2.61	port-year + mon
0.069	0.130	9	51.818	97.680	3.36	year-mon + port
0.075	0.142	10	52.699	99.341	3.73	port-mon + year
0.071	0.134	8	52.726	99.391	2.99	port+year+mon

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.

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.

VIII. Container Monopsony

This section is motivated by a particular quirk of the cost minimization problem that firms would face in a round trip setting and the one-for-one transformation of inputs (inbound loaded and empty containers) into transport services (outbound loaded

Table 21: Jointly Estimated Income-based Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.131	0.180	45	61.401	84.459	20.55	none
0.083	0.115	38	63.967	87.988	17.35	port
0.111	0.153	47	57.436	79.004	21.46	year
0.111	0.153	45	59.264	81.518	20.55	mon
0.083	0.114	36	64.128	88.209	16.44	port+year
0.080	0.110	39	62.921	86.549	17.81	port+mon
0.111	0.153	47	58.716	80.765	21.46	year+mon
0.078	0.108	31	65.610	90.247	14.16	port-year
0.111	0.152	44	59.028	81.195	20.09	year-mon
0.080	0.110	39	61.791	84.995	17.81	port-mon
0.072	0.100	33	63.906	87.903	15.07	port-year + mon
0.076	0.105	36	64.100	88.170	16.44	year-mon + port
0.080	0.109	39	61.957	85.223	17.81	port-mon + year
0.057	0.079	27	62.860	86.465	12.33	port^year^mon
0.079	0.109	36	63.977	88.001	16.44	port+year+mon

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.

containers). Suppose trade is imbalanced and the net importer country generates a positive amount of outbound empties ($e_{ji} > 0$). In this case the output of transport services is a function of these two inputs.

$$l_{ij} = f(l_{ji}, e_{ji})$$

Since container flows are assumed to be balanced between countries, this would imply that transport services from i to j are equal to total container inflows at port i, or, $l_{ij} = f(l_{ji}, e_{ji}) = l_{ji} + e_{ji}$, our usual profit function constraint in a trade imbalance setting. Taking the ratio of marginal products with respect to these two inputs:

$$\text{MRTS} = \frac{MP_{l_{ji}}}{MP_{e_{ji}}} = \frac{\partial f(l_{ji}, e_{ji})/\partial l_{ji}}{\partial f(l_{ji}, e_{ji})/\partial e_{ji}} = 1 = \frac{c_{ji}}{r_{\overset{\leftrightarrow}{ij}}} = \text{ Input Price Ratio}$$

Consider a conventional MRTS in a transport setting, where capital K and labour

Table 22: Import-Specific Income-based Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.170	0.196	29	78.826	90.925	13.12	none
0.123	0.142	9	86.246	99.484	4.07	port
0.133	0.153	25	79.163	91.314	11.31	year
0.130	0.150	26	79.066	91.202	11.76	mon
0.123	0.142	6	86.528	99.810	2.71	port+year
0.123	0.142	10	86.235	99.471	4.52	port+mon
0.131	0.151	26	79.066	91.202	11.76	year+mon
0.127	0.146	8	85.387	98.493	3.62	port-year
0.133	0.153	25	81.085	93.531	11.31	year-mon
0.120	0.138	6	86.615	99.910	2.71	port-mon
0.125	0.144	7	85.512	98.637	3.17	port-year + mon
0.122	0.141	6	86.521	99.801	2.71	year-mon + port
0.120	0.138	6	86.615	99.910	2.71	port-mon + year
0.123	0.142	7	86.520	99.800	3.17	port+year+mon

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.

L inputs generate a transport service Y. Normally the MRTS varies along a given isoquant, given different bundles of inputs z_j. For example, should the capital-labor ratio be particularly high, a relatively more capital-intense input bundle that generates the same of output, $\bar{Y}$, requires significantly more units of capital compared to labor-intense input bundle. The input price ratio between capital and labor is fixed across all possible consumption bundles. A cost minimizing firm selects an input bundle where MRTS is tangent to a constant price ratio.

In the container redistribution case, the MRTS is instead fixed to a value of 1 across all consumption bundles, which under constant input price ratios implies corner solutions where a firm will only utilize the cheapest input. To introduce a unique solution on the net importer side which features positive container outflows in both empty and loaded units, I use a loaded container input price that increases in the level loaded container inputs.[31] This yields variation in the input price ratio

[31] Intuition: Additional loaded containers on a net importer route would imply a longer duration with respect to unloading and cleaning at the net exporter port before the containers are ready to be utilized as inputs. Each loaded container takes more time relative to an empty. The shipping

Table 23: Export-Specific Income-based Loading Factors

Weighted	Weighted (M)	Negative LFs	% Trade	% Trade (M)	% Neg Coeff	Fixed Effects
0.085	0.160	8	52.334	98.629	3.86	none
0.073	0.137	7	52.573	99.078	3.38	port
0.075	0.141	9	52.691	99.301	4.35	year
0.074	0.139	13	52.492	98.927	6.28	mon
0.074	0.140	6	52.614	99.157	2.90	port+year
0.071	0.135	8	52.572	99.076	3.86	port+mon
0.076	0.143	11	52.682	99.284	5.31	year+mon
0.062	0.117	5	52.959	99.806	2.42	port-year
0.077	0.144	11	52.612	99.152	5.31	year-mon
0.075	0.142	11	52.567	99.067	5.31	port-mon
0.058	0.110	5	53.033	99.945	2.42	port-year + mon
0.071	0.133	7	52.573	99.078	3.38	year-mon + port
0.077	0.145	11	52.566	99.065	5.31	port-mon + year
0.073	0.138	8	52.368	98.692	3.86	port+year+mon

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.

Table 24: RMSE of US - E. Asian Container Flow Ratios

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

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.

service cannot commence until the last arriving loaded unit is processed and emptied. Since the first "processed" loaded container input is not usable until the last loaded container input is prepared,

Table 25: RMSE of US-European Container Flow Ratios

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.

rather than the MRTS, given variation in input bundles. Tangency occurs at the level of loaded containers l_{ji} necessary to set $c_{ji}(l_{ji}) = r_{\overset{\leftrightarrow}{ij}}$, where $c'_{ji}(l_{ji}) > 0$.

The resulting profit maximization problem can be expressed as follows.

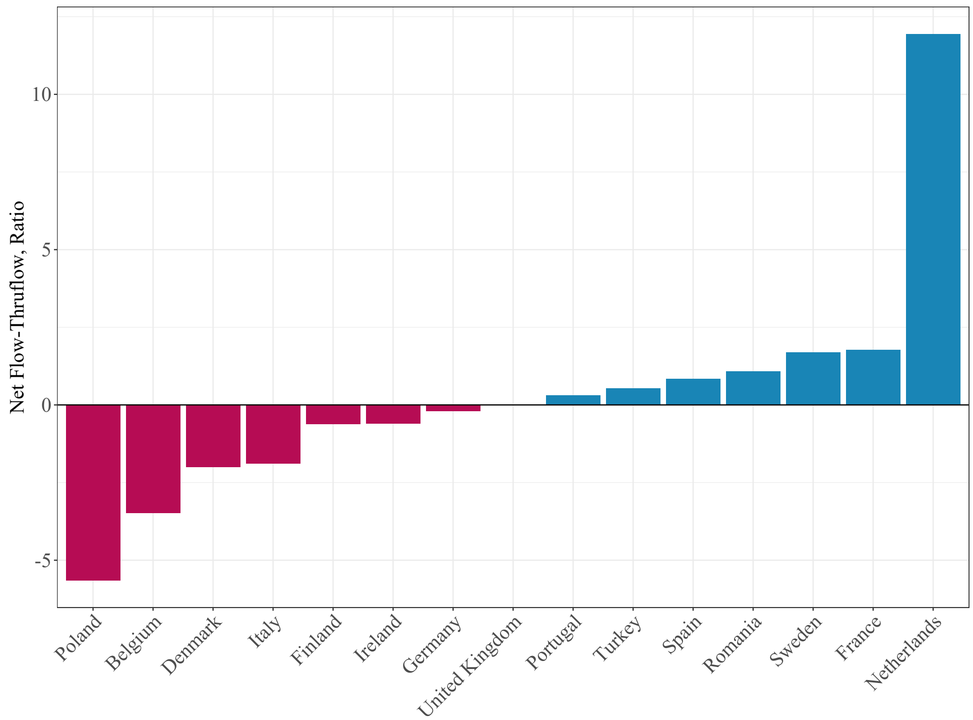
$$\pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - c_{ij}(l_{ij})l_{ij} - c_{ji}(l_{ji})l_{ji} - r_{\overset{\leftrightarrow}{ij}}(e_{ij} + e_{ji}) \tag{24}$$
$$\text{s.t. } l_{ij} + e_{ij} = l_{ji} + e_{ji},$$

There are a number of ways of introducing this increasing input cost parameter. I resort to using the simplest possible expressions, where loaded container input prices increase linearly with respective quantities.

As displayed in Figure 1, the inclusion of rising input prices for one particular input eliminates the possibility of corner solutions, as arbitrage opportunities across input prices are eliminated by a perfectly competitive market. The higher slope of $c_{ji}(l_{ji})$ implies there is a greater cost or more rapid elevating trade-off associated with loading containers at the net importer country compared to the net exporter country. Upon intersection with the input price of empty containers, the loaded container quantity is identified.

I represent this accumulating time challenge with a rising input price per loaded container input.

Figure 15: European Specialization by Net Flow Status (2017)



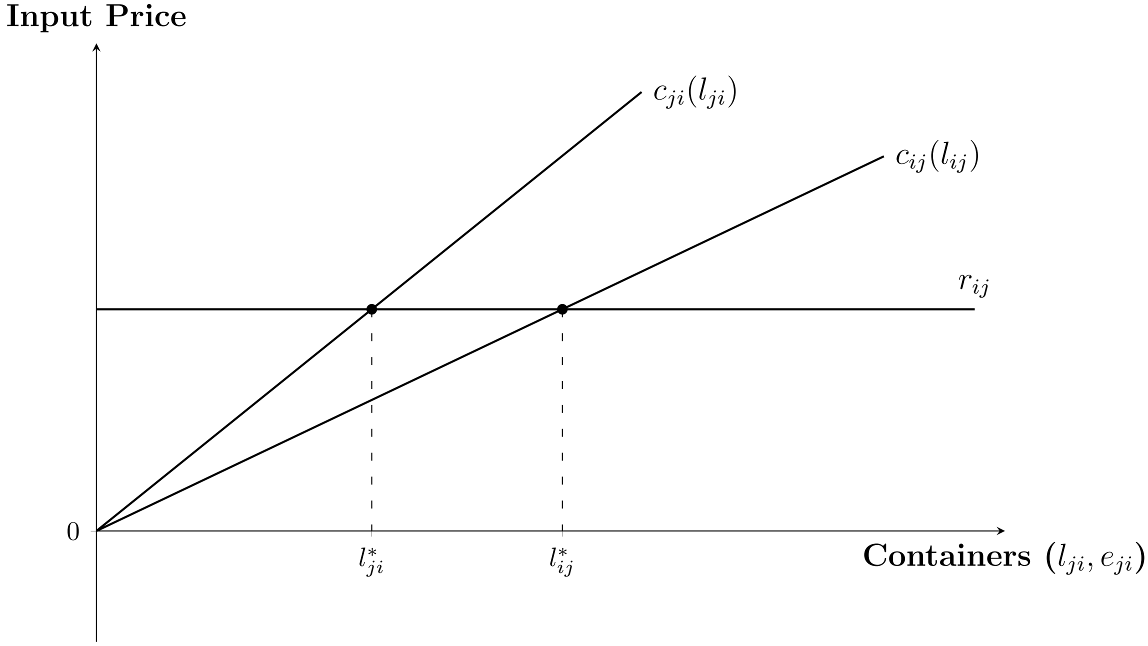
Note: The net flow to thruflow ratio uses inflows less outflows of loaded and empty container units divided by the total flow of loaded & empty container unit traffic. This 2017 data is sourced from "Volume of containers transported to/from main ports by direction, partner entity, container size and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

The relative differences in slopes establish the capacity $\max\{l_{ji}, l_{ij}\}$, empty container load $|l_{ij} - l_{ji}|$ and associated input prices of providing a shipping service. These differences should be representative of exogenous supply and demand factors. For example, should relative demand for l_{ij} increase due to an exogenous preference shock, the slope of $c_{ji}(l_{ji})$ should increase and the slope of $c_{ij}(l_{ij})$ should decrease, causing the trade imbalance displayed above to widen, shipping capacity to increase and empty, $e_{ji} = l_{ij} - l_{ji}$ container flows to rise.

I display two variations and solve for both balanced and imbalanced trade.

1. This first form of input price rises as loaded container inputs rise on route ji. The producer will continue to stack loaded containers onto the 'backhaul' route until the input price is equal to the constant input price of an empty container, e_{ji}. Form: $c_{ji}(l_{ji}) = \theta_{ij} l_{ji}$

Figure 16: Input Price by Loaded Container



2. The inclusion of an added loaded container input, l_{ji}, yields the corresponding freight rate, T_{ji} but comes at the cost of a percentage θ_{ij} of a completed 'full' haul trip's from i to j, T_{ij}. The percentage scales as the loaded input rises. This adjustment captures hows the increased velocity that round trips can complete laps at in cases where the 'backhaul' features a relatively greater level of empties per container input. Form: $c_{ji}(l_{ji}) = \theta_{ij}T_{ij}l_{ji}$

Case I: Balanced Trade

The production function for transport services appears as $l_{ij} = f(l_{ji})$, where the marginal product of the input (MP^L_{ij}) is equal to 1 since $l_{ij} = l_{ji}$. Plugging this updated production constraint into the profit maximization problem of equation (11), the problem becomes analogous with Section 1.2.1 and Wong (2022). Using the first increasing input price function, the transport operator problem becomes:

$$\max_{\{l_{ij}\}} \ \pi_{\underset{ij}{\leftrightarrow}} = T_{ij}l_{ij} + T_{ji}l_{ij} - (\theta_{ij}l_{ij})l_{ij} - (\theta_{ji}l_{ij})l_{ij}$$

$$\text{FOC:} \ \frac{\partial \pi}{\partial l_{ij}} = 0 \implies T_{ij} + T_{ji} = 2\theta_{ij}l_{ij} + 2\theta_{ji}l_{ij}$$

$$l_{ij} = l_{ji} = \frac{T_{ij} + T_{ji}}{2(\theta_{ij} + \theta_{ji})} \tag{25}$$

Consider the inverse demand function implied by equation (4).

$$T_{ij} = \frac{\epsilon - 1}{\epsilon} a_{ij} l_{ij}^{-\frac{1}{\epsilon}} - w_i \tau_{ij}$$

Substituting out freight rates in equation (12),

$$l_{ij} = l_{ji} = \frac{\frac{\epsilon-1}{\epsilon} a_{ij} l_{ij}^{-\frac{1}{\epsilon}} - w_i\tau_{ij} + \frac{\epsilon-1}{\epsilon} a_{ji} l_{ji}^{-\frac{1}{\epsilon}} - w_j\tau_{ji}}{2(\theta_{ij} + \theta_{ji})} = \frac{\frac{\epsilon-1}{\epsilon}(a_{ij} + a_{ji}) l_{ij}^{-\frac{1}{\epsilon}} - w_i\tau_{ij} - w_j\tau_{ji}}{2(\theta_{ij} + \theta_{ji})}$$

Appears to be a non-linear solution. Below I detail a case in which the $w_i\tau_{ij}$ terms do not feature. In this scenario, I divide by $(l_{ij})^{-\frac{1}{\epsilon}}$ to solve for l^*_{ij},

$$(l^*_{ij})^{1+\frac{1}{\varepsilon}} = \frac{\epsilon - 1}{\epsilon} \frac{a_{ij} + a_{ji}}{2(\theta_{ij} + \theta_{ji})} \implies l^*_{ij} = \left(\frac{\epsilon - 1}{\epsilon} \frac{a_{ij} + a_{ji}}{2(\theta_{ij} + \theta_{ji})} \right)^{\frac{\epsilon}{1+\epsilon}}$$

Substituting this expression into the inverse demand function, the equilibrium freight rates are;

$$\begin{aligned}
T^*_{ij} =& \frac{\epsilon - 1}{\epsilon} a_{ij} \left(\left(\frac{\epsilon - 1}{\epsilon} \frac{a_{ij} + a_{ji}}{2(\theta_{ij} + \theta_{ji})} \right)^{\frac{\epsilon}{1+\epsilon}} \right)^{-\frac{1}{\epsilon}} \\
=& \frac{\epsilon - 1}{\epsilon} a_{ij} \left(\frac{\epsilon - 1}{\epsilon} \frac{a_{ij} + a_{ji}}{2(\theta_{ij} + \theta_{ji})} \right)^{-\frac{1}{1+\epsilon}} \\
=& \left(\frac{\epsilon - 1}{\epsilon} \right)^{1-\frac{1}{1+\epsilon}} a_{ij} \left(\frac{2(\theta_{ij} + \theta_{ji})}{a_{ij} + a_{ji}} \right)^{\frac{1}{1+\epsilon}} \\
=& \left(\frac{\epsilon - 1}{\epsilon} \right)^{\frac{\epsilon}{1+\epsilon}} a_{ij} \left(\frac{2(\theta_{ij} + \theta_{ji})}{a_{ij} + a_{ji}} \right)^{\frac{1}{1+\epsilon}}
\end{aligned}$$

Shifting to the increasing input price function based on opportunity cost and round trip velocity, solving the model involves the following steps.

$$\begin{aligned}
&\max_{\{l_{ij}\}} \; \pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ij} - (\theta_{ji}l_{ij}T_{ji})l_{ij} - (\theta_{ji}l_{ij}T_{ij})l_{ij} \\
&\text{FOC:} \; \frac{\partial \pi}{\partial l_{ij}} = 0 \implies T_{ij} + T_{ji} = 2\theta_{ij}T_{ij}l_{ij} + 2\theta_{ji}T_{ji}l_{ij} \\
&l^*_{ij} = l^*_{ji} = \frac{T_{ij} + T_{ji}}{2(\theta_{ij}T_{ij} + \theta_{ji}T_{ji})}
\end{aligned} \tag{26}$$

A similar non-linear solution case is arrived upon.

Case II: Imbalanced Trade

The production function for transport services on the net exporter route is $l_{ij} = f(l_{ji}, e_{ji})$, where the marginal product of a loaded input (MP^L_{ij}) is equal to the marginal product of an additional empty input (MP^E_{ij}), since $l_{ij} = l_{ji} + e_{ji}$. In this case the marginal rate of technical substitution, $\frac{MP^L_{ij}}{MP^E_{ij}}$, is equal to 1. Using the first form of the increasing input cost function, the profit maximization problem can be expressed as:

$$\begin{aligned}
&\max_{\{l_{ij}, l_{ji}, e_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - (\theta_{ij}l_{ji})l_{ji} - (\theta_{ji}l_{ij})l_{ij} - r_{\overset{\leftrightarrow}{ij}}(0 + e_{ji}) \text{ s.t. } e_{ji} = l_{ij} - l_{ji} \\
&\max_{\{l_{ij}, l_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ji} - (\theta_{ij}l_{ji})l_{ji} - (\theta_{ji}l_{ij})l_{ij} - r_{\overset{\leftrightarrow}{ij}}(l_{ij} - l_{ji})
\end{aligned}$$

FOC:

$$\begin{aligned}
\frac{\partial \pi}{\partial l_{ij}} = 0 &\implies T_{ij} - 2\theta_{ji}l_{ij} - r_{\overset{\leftrightarrow}{ij}} = 0 \\
\frac{\partial \pi}{\partial l_{ji}} = 0 &\implies T_{ji} - 2\theta_{ij}l_{ji} + r_{\overset{\leftrightarrow}{ij}} = 0
\end{aligned}$$

Supply and inverse supply of transport services can be expressed as follows, implying an upward sloping supply curve.

$$l_{ij}^S = \frac{T_{ij} + r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ji}} \quad , \quad l_{ji}^S = \frac{T_{ji} - r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ij}} \quad , \quad T_{ij}^S = 2\theta_{ji} l_{ij} + r_{\overset{\leftrightarrow}{ij}} \quad , \quad T_{ji}^S = 2\theta_{ij} l_{ji} - r_{\overset{\leftrightarrow}{ij}}$$

Using equation (4), the demand for these goods are downward sloping in freight rates, points of intersection can be identified.

$$\begin{aligned} l_{ij}^D &= \left(\frac{\epsilon}{1-\epsilon}\frac{1}{a_{ij}}\right)^{-\epsilon} \left(w_i \tau_{ij} + T_{ij}^*\right)^{-\epsilon} &&= \frac{T_{ij}^* + r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ji}} = l_{ij}^S \\ T_{ij}^D &= \frac{\epsilon - 1}{\epsilon} a_{ij} l_{ij}^{*-\frac{1}{\epsilon}} - w_i \tau_{ij} &&= 2\theta_{ji} l_{ij}^* + r_{\overset{\leftrightarrow}{ij}} = T_{ij}^S \end{aligned}$$

In this case, the round trip effect does not present itself. Ships are not setting maximum capacity due to circumstances pertaining to both i and j. Need an expression in which these equilibrium outcomes of price and quantity reflect use of $\{a_{ij}, a_{ji}, \tau_{ij}, \tau_{ji}\}$.

Using instead the increasing function based on opportunity cost of a slower completion rate of round trips:

$$\max_{\{l_{ij}, l_{ji}, e_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij} l_{ij} + T_{ji} l_{ji} - (\theta_{ij} l_{ji} T_{ij}) l_{ji} - (\theta_{ji} l_{ij} T_{ji}) l_{ij} - r_{\overset{\leftrightarrow}{ij}}(0 + e_{ji}) \text{ s.t. } e_{ji} = l_{ij} - l_{ji}$$

$$\max_{\{l_{ij}, l_{ji}\}} \pi_{\overset{\leftrightarrow}{ij}} = T_{ij} l_{ij} + T_{ji} l_{ji} - (\theta_{ij} l_{ji} T_{ij}) l_{ji} - (\theta_{ji} l_{ij} T_{ji}) l_{ij} - r_{\overset{\leftrightarrow}{ij}}(l_{ij} - l_{ji})$$

FOC:

$$\begin{aligned} \frac{\partial \pi}{\partial l_{ij}} = 0 &\implies T_{ij} - 2\theta_{ji} T_{ji} l_{ij} - r_{\overset{\leftrightarrow}{ij}} = 0 \\ \frac{\partial \pi}{\partial l_{ji}} = 0 &\implies T_{ji} - 2\theta_{ij} T_{ij} l_{ji} + r_{\overset{\leftrightarrow}{ij}} = 0 \end{aligned}$$

$$l_{ij}^S = \frac{T_{ij} - r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ij} T_{ji}} \quad , \quad l_{ji}^S = \frac{T_{ji} + r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ji} T_{ij}}$$

Using the inverse demand function implied in equation (4), the solutions for quantities become:

$$l_{ij}^{*}=\frac{\frac{\epsilon-1}{\epsilon}a_{ij}l_{ij}^{*-\frac{1}{\epsilon}}-w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ij}\left(\frac{\epsilon-1}{\epsilon}a_{ji}l_{ji}^{*-\frac{1}{\epsilon}}-w_j\tau_{ji}\right)}\quad,\quad l_{ji}^{*}=\frac{\frac{\epsilon-1}{\epsilon}a_{ji}l_{ji}^{*-\frac{1}{\epsilon}}-w_j\tau_{ji}+r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ji}\left(\frac{\epsilon-1}{\epsilon}a_{ij}l_{ij}^{*-\frac{1}{\epsilon}}-w_i\tau_{ij}\right)}$$

Rearranging l_{ij}^{*}

$$\begin{aligned}
2\theta_{ij}(\frac{\epsilon-1}{\epsilon}a_{ji}l_{ji}^{*-\frac{1}{\epsilon}}-w_j\tau_{ji})l_{ij}^{*} &= \frac{\epsilon-1}{\epsilon}a_{ij}l_{ij}^{*-\frac{1}{\epsilon}}-w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}}\\
2\theta_{ij}(\frac{\epsilon-1}{\epsilon}a_{ji}l_{ji}^{*-\frac{1}{\epsilon}})l_{ij}^{*} &= \frac{\epsilon-1}{\epsilon}a_{ij}l_{ij}^{*-\frac{1}{\epsilon}}-w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}}+(w_j\tau_{ji})l_{ij}^{*}\\
2\theta_{ij}\frac{\epsilon-1}{\epsilon}a_{ji}l_{ji}^{*-\frac{1}{\epsilon}} &= \frac{\epsilon-1}{\epsilon}a_{ij}l_{ij}^{*-\frac{1}{\epsilon}-1}-(w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}})l_{ij}^{-1}+w_j\tau_{ji}\\
l_{ji}^{*-\frac{1}{\epsilon}} &= \frac{1}{2\theta_{ij}}\frac{a_{ij}}{a_{ji}}l_{ij}^{*-\frac{\epsilon+1}{\epsilon}}-\frac{1}{2\theta_{ij}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}(w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}})l_{ij}^{-1}+\frac{1}{2\theta_{ij}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}(w_j\tau_{ji})\\
l_{ji}^{*} &= \left(\frac{1}{2\theta_{ij}}\frac{a_{ij}}{a_{ji}}l_{ij}^{*-\frac{\epsilon+1}{\epsilon}}-\frac{1}{2\theta_{ij}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\left(w_i\tau_{ij}-r_{\overset{\leftrightarrow}{ij}}\right)l_{ij}^{-1}+\frac{1}{2\theta_{ij}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ji}}\left(w_j\tau_{ji}\right)\right)^{-\epsilon}\\
l_{ij}^{*} &= \left(\frac{1}{2\theta_{ji}}\frac{a_{ji}}{a_{ij}}l_{ji}^{*-\frac{\epsilon+1}{\epsilon}}-\frac{1}{2\theta_{ji}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\left(w_j\tau_{ji}-r_{\overset{\leftrightarrow}{ij}}\right)l_{ji}^{-1}+\frac{1}{2\theta_{ji}}\frac{\epsilon}{\epsilon-1}\frac{1}{a_{ij}}\left(w_i\tau_{ij}\right)\right)^{-\epsilon}
\end{aligned}$$

In this case I have two equations and two unknowns, but the explicit solutions for $\{l_{ij}, l_{ji}\}$ are not clear nor would the associated comparative statics be. Likely need to reconsider another method of going about solving this model, or else go down a computational route where the comparative statics can only be assessed through simulation. The benefit of this approach would be incorporating round trip effects in an unbalanced trade setting.

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