Unconventional Protectionism in Containerized Shipping

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Abstract

The containerized shipping market operates like a bus system with vessels assigned to 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 must redistribute 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 US container traffic being consistently balanced 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 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 container returns, I find evidence to suggest that these backfiring effects on opposite-leg routes intensify.

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1. Introduction

According to Notteboom et al. (2022), 70 percent of the value of international trade occurs via maritime transport, two-thirds of which is attributed to containerized shipping. These services specialize in providing round trip voyages that operate in a bus-like manner. Key ports are routinely visited back-and-forth between specific origin-destination combinations. Containers are redistributed within these continuous loops of transport services, leading to a persistent circulation of available transport equipment. In cases of imbalanced demand and asymmetric shipping volumes, container redistribution activity will feature empty containers. This phenomenon introduces the *empty container redistribution 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 the scale of empty redistribution contributes to increased costs for vessel-owning intermediaries, which may alter decisions regarding allocations of vessel capacity, freight rate pricing and trade outcomes on round trip routes. Although the management of empty container redistribution 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 redistribution. A portion of this bill requires the Federal Maritime Commission (FMC) to both define and prohibit the 'unreasonable refusal to deal or negotiate with respect to vessel space accommodations provided by an Ocean Common Carrier'. In other words, the FMC has been tasked with the role of *limiting* the extent to which transport operators refuse allocating portions of vessel capacity to US exports in favor of transporting additional empty containers. Given the interdependency of bilateral trade flows in a round trip setting, it is unclear how restricting empty container outflows could impact the containerized import market on opposite legs of round trips servicing the US.

In this paper, I examine container redistribution in a model of round trip trade and estimate counterfactual scenarios in which restrictions to empty container outflows influence US trade outcomes. In order to capture the intent of this unconventional trade policy, I consider the effects of an empty container outflow (ECO) quota, thereby reallocating vessel space towards US exporters. Using the comparative statics of the resulting model and novel data of port-level loaded & empty container traffic, I establish three key facts; (i) the scale of the empty container redistribution problem grows as asymmetries in shipping volumes intensify, (ii) upon accounting for empty container flows across US ports, national bilateral flows of total container flows – combining both empty and loaded – are consistently balanced over time, and (iii) the size of port container traffic is predictive of the role each location plays – large ports such as Los Angeles & New York are persistent net inflows of containers while mid-tier ports are net outflows. Findings (ii) and (iii) suggest that the US maintains an interdependent container redistribution system that is reliant on the accessibility of inter-modal transport and upon aggregation across ports, forms a balanced container flow network at the national level. Under a regime of ECO quotas, I find that restricting the return of empty transport equipment backfires for the US policymaker. Constraining the redistribution of empty containers contributes to an 18.2% decline in round trip shipping capacity, a 17.3% decline in US containerized imports and an 8.2% reduction in the total value of US containerized trade.

This paper contributes to three strands of international trade literature (i) endogenous transport costs; (ii) theoretical approaches towards representing imbalanced round trip trade; (iii) resurgent protectionism in trade policy.

First, this paper features endogenous trade costs and emphasizes the importance of allowing variation in transport costs to affect trade outcomes. These costs represent an increasingly prominent factor in determining overall trade costs, given the persistent decline of associated import tariffs over the past six decades. 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 trade models handled these costs in an ad-hoc and exogenous manner[1], more recent theoretical frameworks use a variety of endogenous approaches (Bonadio, 2022; Hayakawa et al., 2020; Irarrazabal et al., 2015). For example, Atkin and Donaldson (2015) and Brancaccio et al. (2020) both feature differences in market power across intermediary transport service operators determining variation in transport costs. Allen and Arkolakis (2022) and Wong and Fuchs (2022) highlight how differences in the underlying quality of infrastructure and the volume of traffic congestion across regions can also explain variation in transport costs. Using novel 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.

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[1] 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).

Second, this paper relates to theory surrounding round trip transport services. Given that the volume 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 associated 'backhaul' freight rate of this leg of a round trip will drop 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 matching process into the model. Ishikawa and Tarui (2018) solves for positive bilateral freight rates by introducing imperfect competition. I contribute an alternative remedy to this challenge by 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 commits to redistributing empties. Under this imbalanced trade setting, the marginal revenue of shipping one additional loaded container on the high-volume route is equal to the cost of handling that loaded unit plus the cost of returning one additional empty container. In contrast, transporting one additional loaded unit on the low-volume leg of a round trip occupies an existing empty, resulting in the associated marginal cost being equal to the loaded handling cost less the cost of returning one empty unit. Under the appropriate 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).

Third and lastly, I use a quantitative approach to estimate key model primitives, such as per-unit container handling costs, and evaluate the effects of a policymaker restricting empty outflows in favor of stimulating US exports. This paper adds to a collection of studies examining the effects of recent resurgences in protectionist trade policies (Sampson, 2017; Bown, 2021; Fajgelbaum and Khandelwal, 2022). While there is a well-documented understanding how of demand-side interventions influence trade outcomes (e.g., tariffs & quotas), OSRA22 targets supply-side elements of trade by constraining the availability of transport equipment. As my findings highlight, this policy tool is particularly precise in targeting net exporters, particularly those with a greater reliance on empty containers from the US. To the best of my knowledge, this study represents the first to consider this unconventional form of protectionism via transport policies. I find that although exports are stimulated by empty restrictions, the reduction vessel capacity and opposite-leg imports decline contributes to a backfiring of policy in which overall trade activity declines. Furthermore, I highlight that representing the varying margins of reliance on empty container redistribution across US trade partners are key in this setting.

The remainder of the paper proceeds as follows. In the next section, I detail the how container redistribution functions and outline the factors which contribute to empty container redistribution. Section 3 outlines a partial equilibrium model of containerized trade, which features imbalanced goods flows and incorporates a 'no excess capacity' constraint on container unit utilization which ensures balanced container flows between origin-destination pairs. Section 4 provides a brief description of the data I use and Section 5 presents a series of stylized facts of containerized trade. In Section 6, I calibrate and estimate the exogenous parameters of this empty container model and consider the counterfactual effects of government intervention aimed at limiting the outflow of empty container units from the US. I first specify a simple two–entity scenario between the US and the rest of the world. I then account for extensive and intensive margins of country-specific reliances on empty container redistribution in a multi-country round trip setup and highlight a greater magnitude of trade outcome deterioration through greater adjustments in trade activity and higher import prices. 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. This catapulted forth a flexible 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 supply chain networks of lower cost and higher delivery time risk (Carreras-Valle, 2022).

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 available container inventory across locations, container redistribution features empty units on the backhaul (lower volume) leg of a given round trip. This is known as an inventory management problem in which a cost minimizing assignment of container capacity and flows must be determined. As Lee and Song (2017) highlights, empty container redistribution 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.

Lee and Song (2017) describes two broad considerations that transport operators face under imbalanced trade on round trip routes; (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 redistribution costs to freight rates and enforces a balanced container flow constraint between nodes such that combinations of loaded and empty container units can be accounted for on the backhaul (lower volume) leg of a given roun dtrip. However, given that I use a static model, I do not featuree decision-making rules that seek to address short-run fluctuations in shipping demand.

The transport logistics literature therefore recognizes the scale of the empty container redistribution 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 & demand volatility. For the purposes of this paper, I focus on the long-term determinants of variation in empty container redistribution, through imbalanced trade. The greater the asymmetry in loaded container flows within a given round trip, the larger the volume of empty container redistribution. Furthermore, the empty container redistribution 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 redistribution 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 function as combinations of loaded and empty container handling costs. The model is static in design and therefore features no time-dynamic elements. Any resulting steady-state equilibrium outcomes should therefore 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 $\overset{\leftrightarrow}{ij}$ 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:

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

where l_{j0} represents the quantity of the numeraire good consumed in country j and l_{ij} represents the quantity of a tradeable variety sourced from country i.[2] 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

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

ij leg of the round trip, τ_{ij}; and (iii) the per-container freight rate, T_{ij}.[3]

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

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 rate times the loaded container quantity. Costs are determined by loaded and empty container inputs used to provide services. The costs of per-unit loaded and empty container handling is represented, respectively, by the set $\{c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\}$.[4] 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.[5] Bilateral flows of container units, irrespective of their loaded status, 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 $\overset{\leftrightarrow}{ij}$. This leads to a prevailing empty redistribution problem and the profit

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[3] Holmes and Singer (2018) highlights an indivisibility of transport costs due to per-container freight rates not varying across based on variation in the usage of containers' cubic volume capacity.

[4] 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.

[5] I highlight the more general case in which all container input prices are equal, regardless of status or route, in Appendix I. 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 by status in input prices across containers.

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.[6] 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: $c_{\overset{\leftrightarrow}{ij}} > r_{\overset{\leftrightarrow}{ij}} \; \forall \; \overset{\leftrightarrow}{ij}$.

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 that are analogous to Wong (2022). Solutions for these expressions are displayed in Appendix II.

$$
\begin{aligned}
&\max_{\{l_{ij}\}} \;\; \pi_{\overset{\leftrightarrow}{ij}} = T_{ij} l_{ij} + T_{ji} l_{ij} - c_{\overset{\leftrightarrow}{ij}} (l_{ij} + l_{ij}) \qquad (4) \\
&\text{FOC:} \;\; \frac{\partial \pi}{\partial l_{ij}} = 0 \implies T_{ij} + T_{ji} = 2 c_{\overset{\leftrightarrow}{ij}}
\end{aligned}
$$

Under a balanced trade assumption with constant input prices, the 'round trip' effect is present. 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.

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.

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[6] 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.

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:

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

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

Upon substituting the balanced container flow constraint into the profit maximization problem, freight rates for both legs of a given round trip $\overset{\leftrightarrow}{ij}$ 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.

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

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.

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

However, variation in empty container handling costs, $r_{\overset{\leftrightarrow}{ij}}$, will have counteracting effects on outcome variables for a given round trip, highlighting a round trip effect in the model. For example, consider a case in which the cost of empty container outflows from country j rises. Not only does this stimulate export activity, as existing cargo space on leg ji is reallocated from container redistribution to exports from j, but in addition, l^*_{ij} declines, which represents the transport capacity allocated to route $\overset{\leftrightarrow}{ij}$. This reflects an overall reduction in transport services on route $\overset{\leftrightarrow}{ij}$ due to the associated cost of maintaining balanced 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 $\overset{\leftrightarrow}{ij}$. Recall for the trade value expression that we assume $\epsilon > 1$.

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

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

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

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

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.

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

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.

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

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, $r_{\overset{\leftrightarrow}{ij}}$, 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: $\frac{\partial T^*_{ij}}{\partial r_{\overset{\leftrightarrow}{ij}}} > 0, \frac{\partial T^*_{ji}}{\partial r_{\overset{\leftrightarrow}{ji}}} > 0, \frac{\partial E^*_{ji}}{\partial r_{\overset{\leftrightarrow}{ij}}} < 0$

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

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

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 $(\Delta E_{ji} > 0)$.[7]

4. Data

I describe the main data set of the paper, which combines monthly US port samples of containerized trade and associated container traffic flows, both for empty and loaded units. I also provide details on the auxiliary tariff and wage data used for the calibration of exogenous parameters throughout the counterfactual analyses of this paper.

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

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

(HS) level. Using this data, I form a balanced panel of the top 14 port locations for containerized trade flows.[8] 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. This second dataset details four separate items: (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. My results are based on a balanced panel of 12 ports between January 2012 and December 2021, 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.

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. In cases of missingness in these time series, I use OECD annualized growth rates of average monthly manufacturing wages to 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.

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[8] 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 (LA), New Orleans (LA) and Jacksonville (FL).

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's as a single entity, which at only this scale of operations maintains balanced container redistribution comparable to the US.

5.1. Empty Shares & Trade Balance Adjustment

Stylized Fact 1. *A positive deviation from the export-import ratio from i to j is correlated with a negative deviation of empty containers 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 implies lower empties as a percentage of total container outflows.

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

I regress two micro-founded models to test this negative relationship empirically,

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

where $\beta < 0$ is the 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. Table 1 shows that a relatively smaller US trade deficit is associated with reductions 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.

Table 1: Trade Flow Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows				
	Outbound		Inbound	
$\left(\frac{\text{Export}}{\text{Import}}\right)^{\text{USD}}$	-0.9575***			
	(0.0687)			
$\left(\frac{\text{Export}}{\text{Import}}\right)^{\text{KG}}$		-0.3909***		
		(0.0288)		
$\left(\frac{\text{Import}}{\text{Export}}\right)^{\text{USD}}$			-0.0253***	
			(0.0062)	
$\left(\frac{\text{Import}}{\text{Export}}\right)^{\text{KG}}$				-0.0327***
				(0.0097)
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.

In Table 2, I use the Net-Gross ratio featured in Brancaccio et al. (2020), and observe further support for this proposed relationship between prevailing imbalance and the size of the empty container redistribution problem. A one unit increase in the exports-oriented net-gross ratio, $\frac{\text{Exports}-\text{Imports}}{\text{Total Trade}}$ is associated with a 0.85 percentage point decline in the share of empties on outbound container shipments originating from the US.

Table 2: Net-Gross Ratio & Empty Shares

Dependent Variable: Empty Container Share of Total Flows				
	Outbound		Inbound	
$\left(\frac{\text{Net Exports}}{\text{Gross Trade}}\right)^{\text{USD}}$	-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)
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.

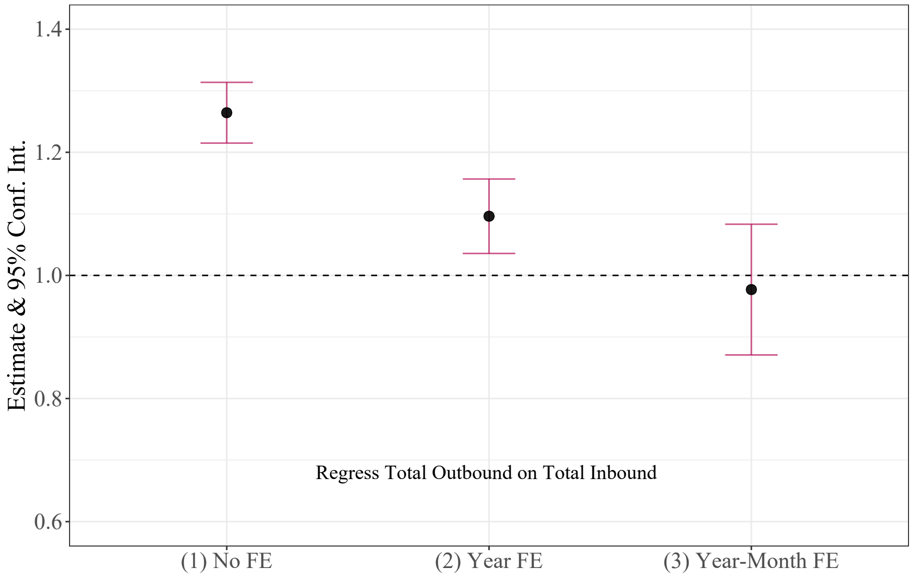
5.2. Balanced Container Flows

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. The US maintains balanced container inflows and outflows consistently across time.*[9]

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 equilbrium model of empty container redistribution.

To address potential seasonality or unobserved shocks occurring throughout the time series, I apply a simple set of regressions that includes year, and year-month fixed effects in a step-wise manner. Using these step-wise fixed effect models, I regress total number of inbound containers on the total number of outbound containers at the port level. Results displayed in Figure 1 yields coefficients which do not statistically differ from 1 at a 95% confidence level.

Figure 1: Balanced National Container Flows



Clustered (month) standard-errors. Total outbound containers summed across a balanced panel of 12 US ports, which includes loaded and empty containers, is regressed on total inbound containers for these same set of ports. Observed total container levels between January 2012 and December 2021 are used. Coefficients are reported in a step-wise manner with additional fixed-effects included in order of: none, year, year-month.

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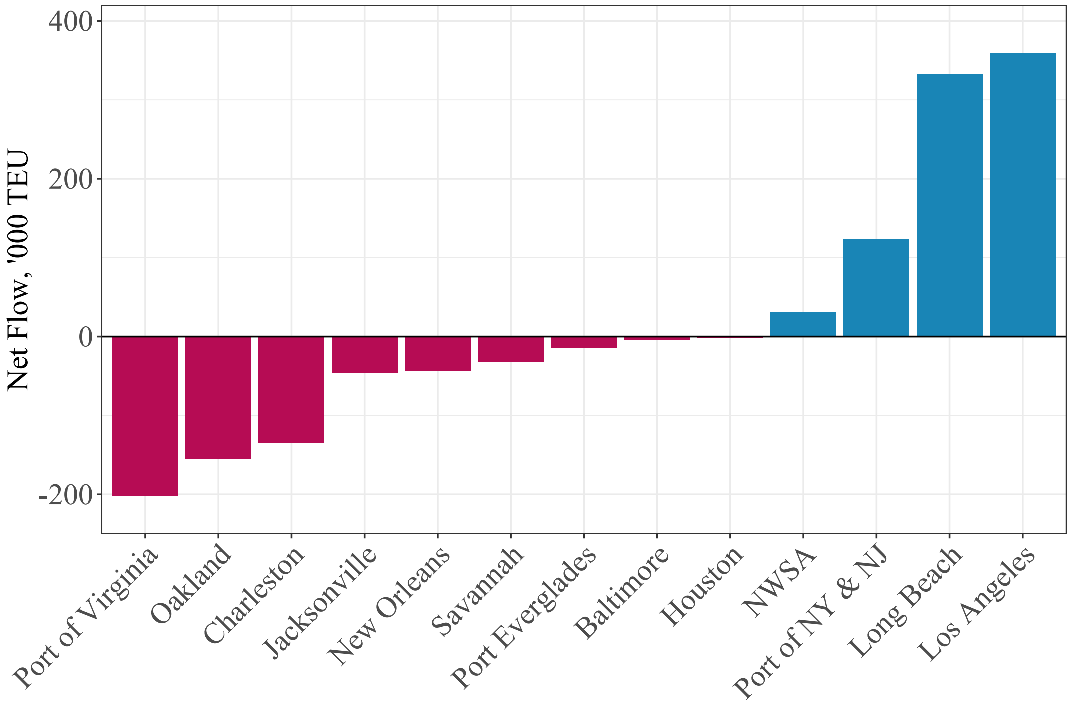
[9] Does not apply unless empty container units are accounted for in each total measure.

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 – which account for both loaded and empty containers – are balanced at the national level, patterns in port-level container flows highlights 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 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 Figure 2, I display annual net differences in total container flows for 2017.

Figure 2: Port Specialization by Net Flow Status (2017)



These statuses are consistent across time. Los Angeles, Long Beach, PANYNJ, and NWSA act as net inflows whereas the remaining set of mid-tier ports are net outflows. As displayed in Figure 3, 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 positions 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 3).

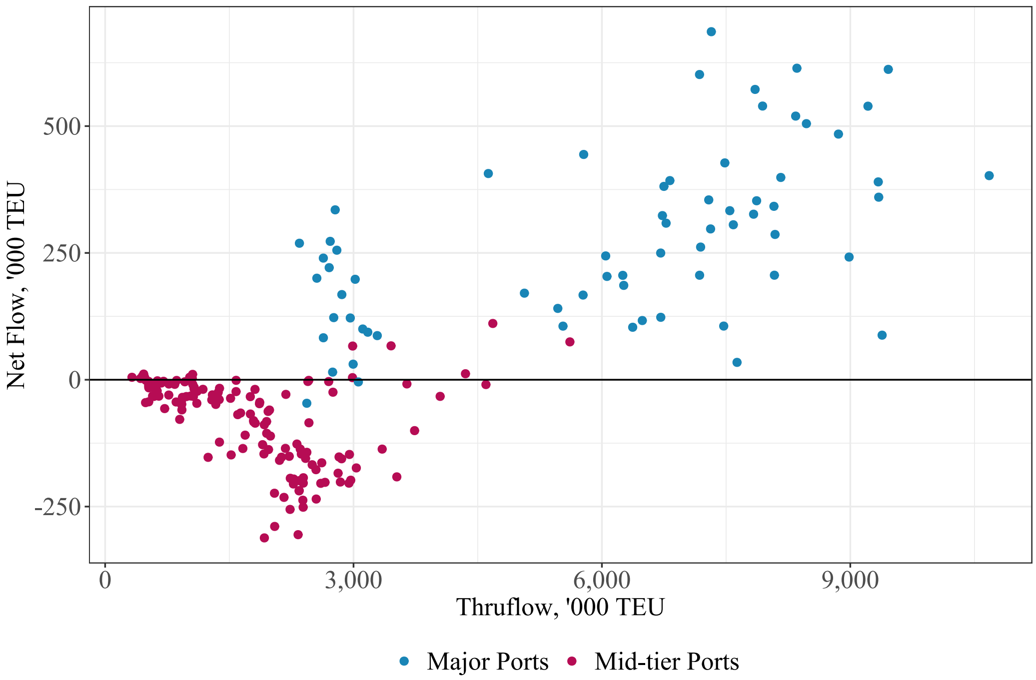
Table 3: Average Containership Gross Tonnage by Port Size

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

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

Given that national bilateral container flows are balanced, yet individual ports 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. 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 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 3: Port Specialization by Total Container Thruflow (2012-2021)



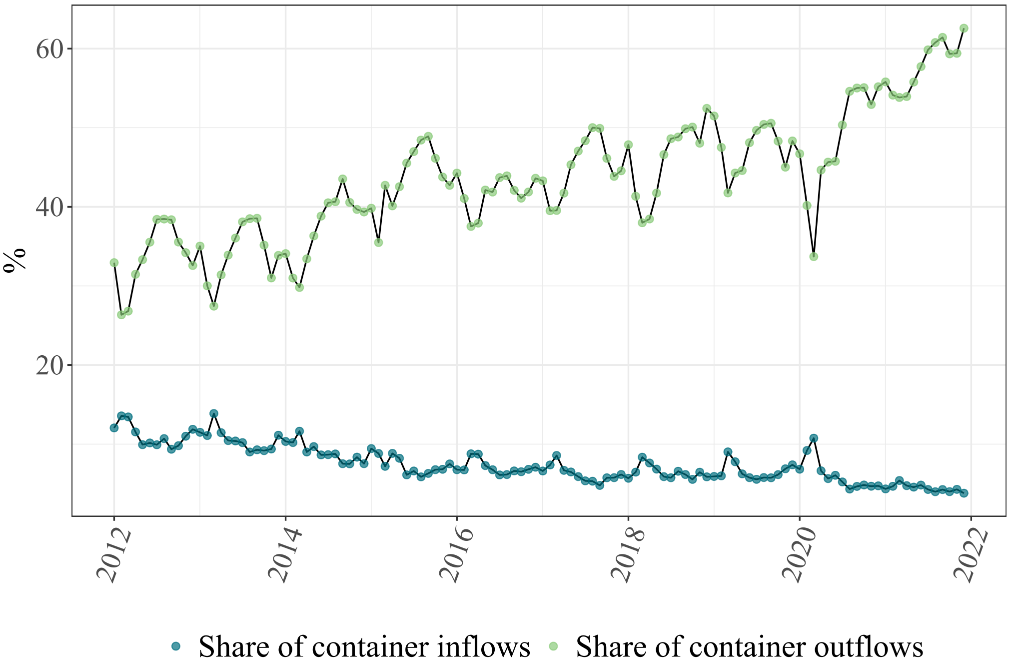
6. Counterfactual

I use the quantitative model featured in Section 3 to conduct a series of counterfactual analyses. In the proceeding section, I begin by outlining the use of 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, which motivates my estimation of bilateral loaded container flows (by TEU) for each US trade partner. By accurately estimating these flows, I can accommodate for 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-empty tax. Relative to a US-RoW representation, accounting for trade partners' varying degrees of reliance on empty container redistributions 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 containerized trade, a single round trip service forms. 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 4, 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 empty container redistribution problem.

Figure 4: Empty Share of Container Movement by Year-Month



Under this setting, I establish a baseline scenario of the model using trade and container traffic data specific to average monthly levels reported in 2017.[10] I use a generalized method of moments (GMM) estimator in which a system of trade and container flow equations, $\{X_{ij}, X_{ji}, l_{ij}, l_{ji}\}$, featured in Equations (8) and (9), represents my endogenous set of moments in the data. I reduce the number of

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

unknown exogenous parameters to 4 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 estimate of 20.96 used in Wong (2022).[11]

While this remedy greatly simplifies a general representation of US round trip trade, the use of net empty flows in a single round trip setting also introduces three key drawbacks; (i) an under-representation of the scale of the empty container redistribution problem, (ii) no distinguishing between net exporter and net importer statuses across US trade partners, and (iii) no acknowledgement of differences across net exporters in terms of their varying scales of reliance on the return of empty containers. 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.

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

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[11] See Appendix section IV 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.

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.[12]

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.

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

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

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[12] 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.

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

$$l^f_{US-j,t} = \sum_{p=1}^{P} l^f_{pt} = \sum_{p=1}^{P}\sum_{k=1}^{K} \beta^{fjk} w^f_{pjkt}, \tag{15}$$

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

$$l^f_{pt} = \sum_{k=1}^{K} \beta^{fk} \sum_{j=1}^{J} w^f_{pjt} + \varepsilon^f_{pt} \tag{16}$$

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.

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. As I will demonstrate, these manufactured commodities represent a large share of the value of containerized goods flows, particularly across US imports.

6.2.2. Loading Factor Estimates

Using these assumptions, I regress Eq. (16) to examine 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 compositional 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 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.

These estimates are generally significant and positive in value.[13] 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.

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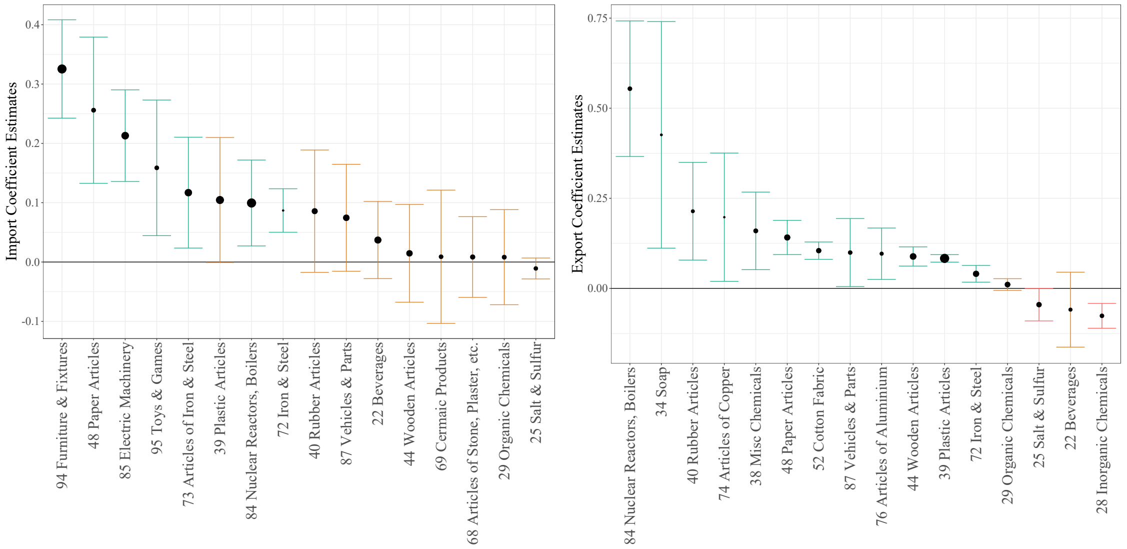
[13] Appendix V provides diagnostic tables which summarise the percentage of positive coefficients and manufacturing-specific coefficients. Additionally, the tables report the percentage of total trade flows and manufactured trade flows that these positive coefficient estimates are associated with. These diagnostics are provided across a range of fixed effects as well as when restricting loading factors to be common across directions of transport.

Figure 5: 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.

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.[14] I therefore focus attention on loading factor estimates specific to the direction in which goods are flowing and generate country–level loaded container flows,

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

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.

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[14] See Table 12 in Appendix V for further details.

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.[15] 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 presented in Table 4, both regions yield highly accurate co-movements in inflows of container unit volumes and adjustments in the relative difference of TEU flows over time. Predictions on outflows are poorer in quality, particularly when focusing on the subset of loaded container volumes transporting manufactured goods to East Asia.

Table 4: Estimates' Correlation with UNCTAD Regional Container Flows

Series	port	port+year	port+mon	py	pm	py+m	ym+p	pm+y	p+y+m
East Asian Inflow (M)	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	0.99	≈ 1	≈ 1
East Asian Outflow (M)	0.52	0.55	0.51	0.54	0.53	0.54	0.56	0.56	0.55
East Asian Ratio (M)	0.98	0.98	0.98	0.95	0.98	0.95	0.98	0.98	0.98
East Asian Inflow	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1	≈ 1
East Asian Outflow	0.53	0.58	0.53	0.56	0.48	0.57	0.58	0.52	0.58
East Asian Ratio	0.99	0.98	0.98	0.91	0.98	0.90	0.98	0.98	0.98
European Inflow (M)	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.98	0.99
European Outflow (M)	0.70	0.70	0.73	0.85	0.74	0.85	0.73	0.73	0.73
European Ratio (M)	0.98	0.96	0.98	0.88	0.95	0.84	0.96	0.93	0.96
European Inflow	0.98	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98
European Outflow	0.76	0.76	0.77	0.85	0.78	0.85	0.77	0.77	0.77
European Ratio	0.99	0.97	0.99	0.90	0.98	0.85	0.98	0.96	0.97

East Asia is comprised of China, Hong Kong, Indonesia, Japan, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. Europe is comprised of Austria, Belgium, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom. (M) for manufactures, otherwise based on all goods.

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.[16] Additionally, I introduce balanced container flow

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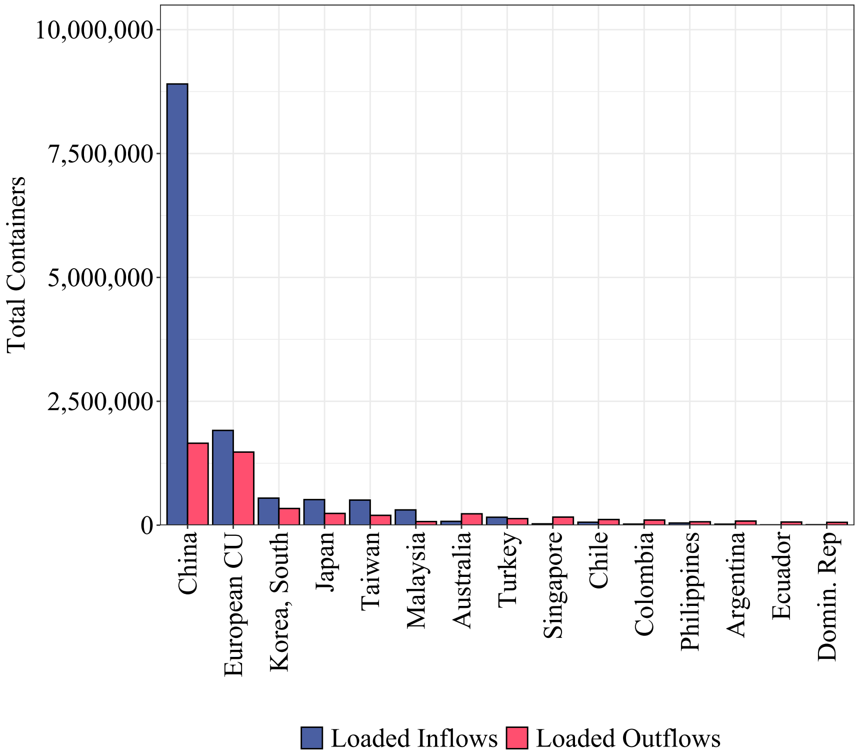
[15] As highlighted in Appendix V, port fixed effects yield the best match in terms of largely positive loading factors.

[16] Following Wong (2022), I use wage levels and tariff rates associated with manufactured goods.

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.[17] 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.[18]

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 6. This limits my use of multi-country estimated bilateral container flows to represent 70% (50%) of containerized import (export) value.

Figure 6: 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).

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

[18] 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 17th 2023.

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 $\left(a_{ij}, a_{ji}, w_i, w_j, \tau_{ij}, \tau_{ji}, c_{\overleftrightarrow{ij}}, r_{\overleftrightarrow{ij}}\right)$ 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.[19] I deflate the value of trade flows and USD-converted wage levels for each trade partner using the Bureau of Labor Statistics Consumer Price Index for all urban consumers, which considers all final good items less food and energy, averaged across major US cities.[20] Lastly, I include 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.

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, $\tilde{\rho} = \left(a_{ij}, a_{ji}, c_{\overleftrightarrow{ij}}, r_{\overleftrightarrow{ij}}\right)$, via GMM.[21] I minimize the object function,

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

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

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[19] 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.

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

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

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, $c_{\overset{\leftrightarrow}{ij}}$, and empty container flows, $r_{\overset{\leftrightarrow}{ij}}$, 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 the wake of a sudden enlargement of the US trade deficit, late into the COVID-19 epidemic, over 50% of outbound container units departed from the US empty. In this subsection, I discuss recent changes to liner shipping regulation through the Ocean Shipping Reform Act of 2022 (OSRA22), which in part 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 made the redistribution of empty container units 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 emptied and 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)*[22] *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 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.[23]

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

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[22] 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"*.

[23] 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.

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 to by 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. More specifically, 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.

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.[24] 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.

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[24] 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 policy backfires, as reflected by the associated decline in vessel capacity on net exporter trade routes and retraction in overall trade value and volume.

6.5. Main Results

As displayed in column 3 of Table 5, a moderate ECO quota stimulates export activity. US exporters flock to relatively cheaper freight rates for round trips 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 36.8%. However, a focus only on this outbound leg of US round trip transport ignores further market developments, known as round trip effects, which may be of interest to the policymaker. Relative to the baseline scenario, a multi-country model of US containerized trade sees a 17.3% 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 1.8% 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 18.2% due to policy introducing an added friction servicing imbalanced volumes of trade. This leads to a retraction in container redistribution. The scale of the empty container redistribution problem as a percentage of total US container outflows falls by 37.2%.

Table 5: Disaggregated Counterfactual Outcomes

US Measures (2017)	US-RoW	Multi-Country
Imports	-17.48	-17.31
Exports	25.65	30.79
Loaded Inflows	-18.27	-19.05
Loaded Outflows	27.09	35.1
Imports Price	0.79	1.75
Exports Price	-1.45	-4.31
Total Value	-9.31	-8.24
Total Volume	-5.76	-4.13
Vessel Capacity (TEU)	-18.27	-18.2
Empty Outflow Share	-34.16	-37.18
Import-Export Ratio	-34.32	-36.78

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

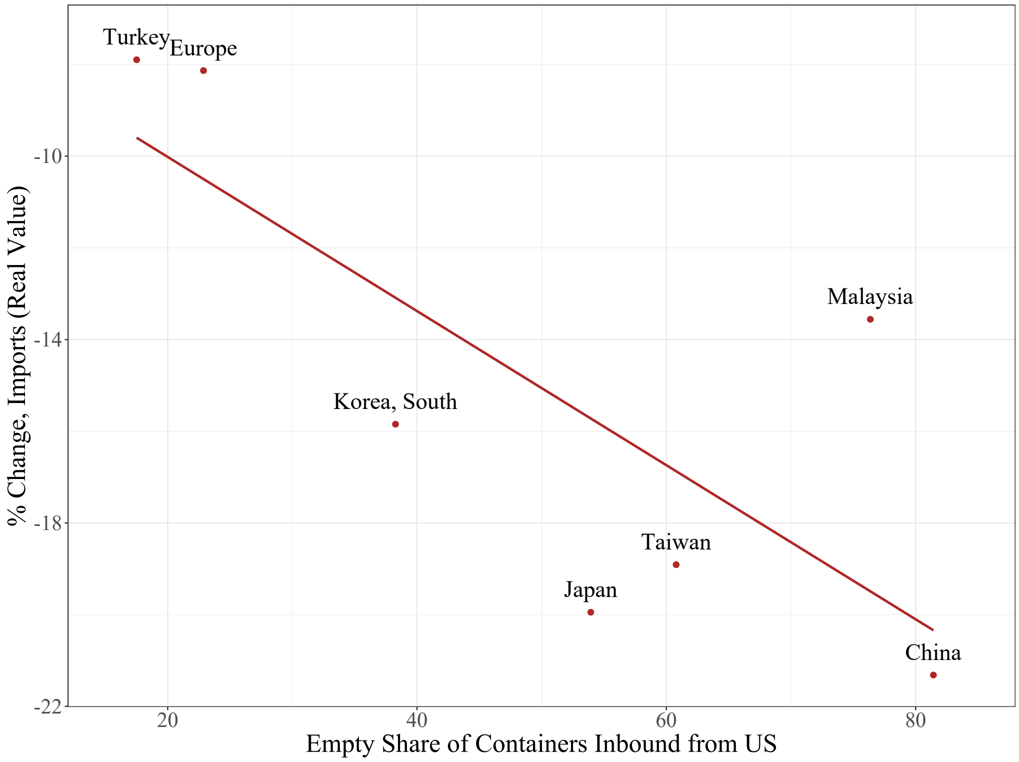
While adjustments in individual flow measures and the trade balance are of interest, understanding changes to the scale of overall trade activity is of the greatest importance in this setting. Should overall trade activity decline, this would signal associated gains from trade reducing in scale. In the case of the multi-country setup, a moderate ECO quota contributes to an 8.2% (4.1%) change 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 5, I list the would-be counterfactual results of this setting, had only aggregated flows of container units been considered along with aggregations of containerized trade flows. Most importantly, this setting ignores which trade partners are reliant on empty container returns and represents the net flow of empty container units, whereas the multi-country setting allows for bilateral gross flows to be featured. Upon calibrating a baseline model in this fashion and introducing an identical $\gamma_{\bar{E}_{ji}=0.4}$ empty container tax, I find that the overall magnitude of shocks to various trade outcomes is generally lower in magnitude. For example, although accounting for heterogeneous reliances on empty container redistribution suggests exports are stimulated, the multi-country analysis yields a 20% greater substitution effect into US exports. 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 redistribution problem and targeting policy effects correctly across multiple countries, rather than relying on aggregated moments in the data.

When jointly considered, these results suggest that government intervention in the redistribution of empty container units may lead to a backfiring effect, in which vessel capacity contracts due to the relatively greater expense associated with servicing trade imbalances. Within trade lanes, exports grow, but this effects are outscaled in level-terms by a reduction in import activity. These findings suggest that 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.

Across the subset of net exporters which engage in containerized trade with the US, the pre-existing scale of the empty container redistribution 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 redistribution yielded the highest declines in imports. As highlighted in Figure 7, East Asian trade partners maintained the highest empty container shares in the predefined baseline scenario. Upon the introduction of a per-unit tax on empty redistribution, 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 7: Import Value by Net Exporter (2017)

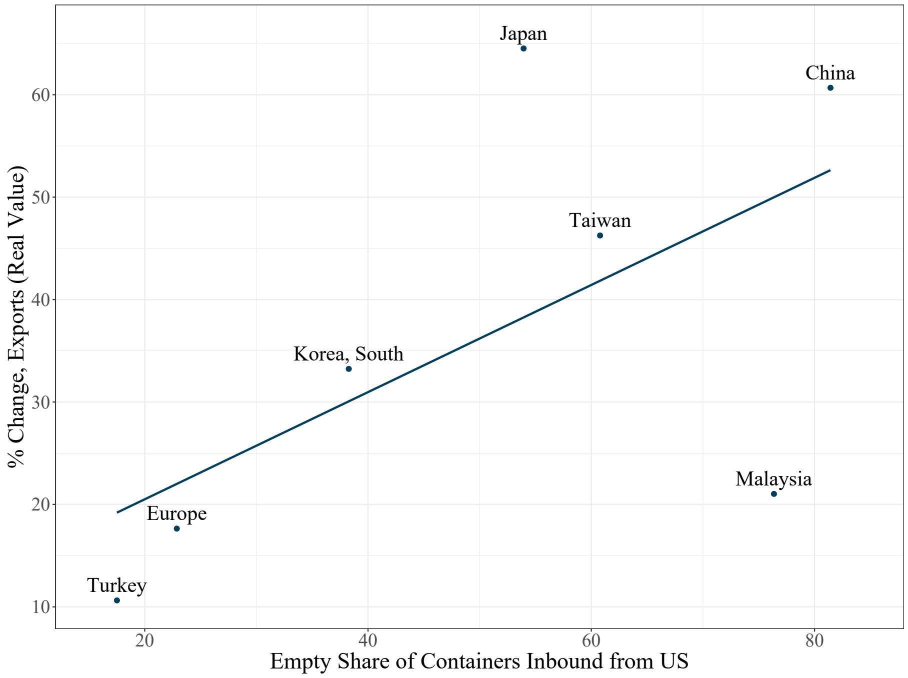


Note: The real value of imports is used, deflated by US CPI for urban areas, less food and energy. The empty share represents $100 * \frac{\text{US-Country Empty Outflows}}{\text{Total US-Country Outflows}}$, and reflects pre-policy shares of total container outflows.

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 8).

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 9, 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.

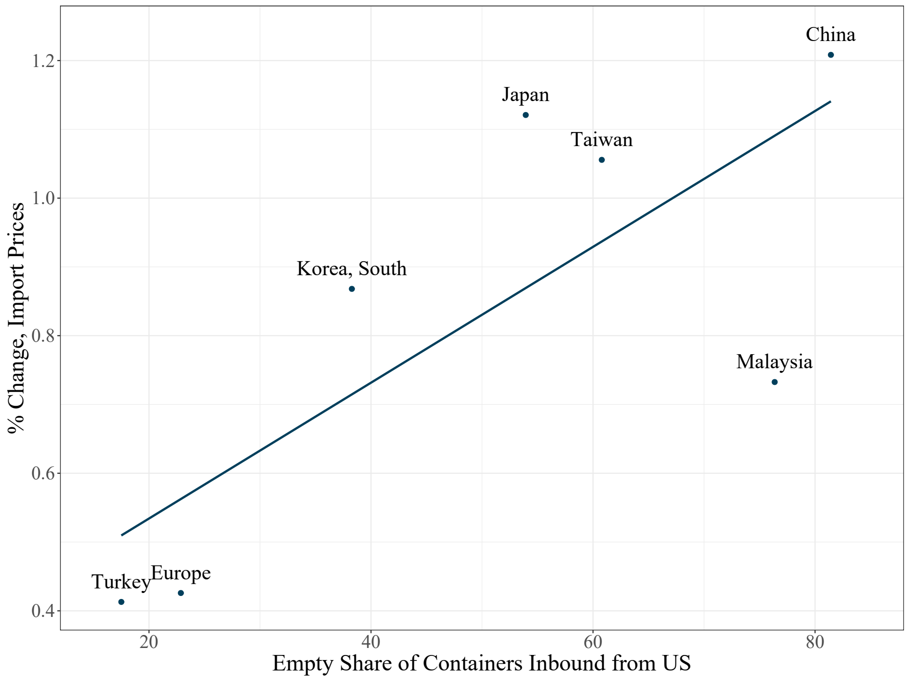
Figure 8: Export Value by Net Exporter (2017)



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.

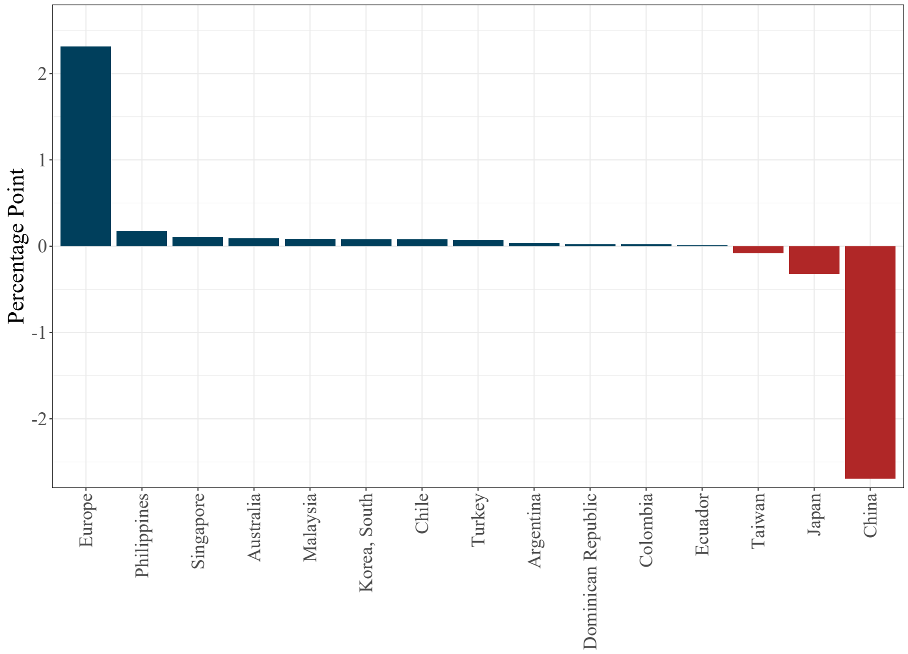
The sizable loss in transport equipment accessibility and the acuteness of this decline on routes with a particularly high dependencies on empty redistribution leads to a noteworthy changes in country shares of the US import market. As displayed in Figure 10, restrictions on empty outflows yield considerably diverse outcomes, where in some cases net exporters gain market shares despite being reliant on empty container redistribution. 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 redistribution, 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 9: 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 $100 * \frac{\text{US-Country Empty Outflows}}{\text{Total US-Country Outflows}}$, and reflects pre-policy shares of total container outflows.

Figure 10: 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 redistribution 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 therefore expands the trade literature's pantry of available 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 the largest ports in the US, representative of 80% of gross container unit traffic, I directly observe flows of empty container units intended to bolster trade services elsewhere in the world. Connecting theory and empirics, this paper is the first to 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 redistribution problem.

I also contribute theoretically to the international trade and transport economics literature through my partial equilibrium model of container redistribution. 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.

Lastly, I estimate and quantitatively evaluate how interfering in the use of this transport technology can affect trade flows. Although the trade field 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 an unconventional form of protectionism in which limitations are placed on how physical transport equipment can be used 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. In the case of this study, I set about introducing a tax on empty container unit outflows through a counterfactual analysis that targets the

US historical average of empty outflows as a percentage of total container outflows. These restrictions are found to contribute to a reduction in the effective capacity of shipping services, introduce greater inflation across imports and result in an overall reduction in both the value and volume of trade activity (summing across imports and exports). Upon accounting for the intensive and extensive margin differences of country-specific dependencies on empty redistribution, I identify far larger magnitudes of effects compared to a simple two-country model of round trip services between the US and rest of the world. My findings highlight that careful consideration is required when interfering with container redistribution and liner shipping regulation. 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."

Going forward, I believe this study adds a further emphasis towards a collective need for granular data with respect to port traffic and container shipping details. I welcome particular changes introduced through OSRA22, which enabled the Federal Maritime Commission to publish a quarterly report that details the total import and export tonnage and the total loaded and empty 20-foot equivalent units per vessel operated by ocean common carriers. As this paper's exercise of estimating country-specific container flows may indicate, further studies of maritime transport require greater knowledge of where containers are originating from, the routes they travel upon and the destinations they ultimately are destined for upon being repurposed. These improvements in data availability would enhance the identification of key transport bottlenecks and better our understanding of countries' joint dependency on efficient transport equipment usage. Furthermore, such data would enable the development of more sophisticated approaches in modelling container redistribution. For example, dynamic modelling would be capable of addressing short-to-medium run effects of disruptions to container availability and port congestion that my partial equilibrium model neglects. Additionally, research that observes complex networks of container redistribution would allow for more accurate demonstrations of how shocks can not only permeate trade outcomes through intra-route round trip effects but also allow for spillover into inter-route round trip effects.

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 $\overset{\leftrightarrow}{ij}$. 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.

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

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

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

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

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

The equilibrium value of trade is simply price times quantity:

$$\begin{aligned} X_{ij}^* &= l_{ij}^* p_{ij}^* \\ &= \left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(\frac{1}{1+\frac{a_{ji}}{a_{ij}}}\left(2c_{\overset{\leftrightarrow}{ij}} + w_i\tau_{ij} + w_j\tau_{ji}\right)\right)^{1-\epsilon} \end{aligned} \tag{22}$$

III. Container Traffic Sample

In Table 6, 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 6: 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	NA	NA

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

IV. 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 $\left(a_{ij}, a_{ji}, w_i, w_j, \tau_{ij}, \tau_{ji}, c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\right)$ 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. [25] 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.[26] 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, $\tilde{\rho} = \left(a_{ij}, a_{ji}, c_{\overset{\leftrightarrow}{ij}}, r_{\overset{\leftrightarrow}{ij}}\right)$ 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 outcomes, $\log(Y^{\text{data}}) - \log(Y^{G})$ and $\bar{W}$ is a weight matrix that assists in speeding the identification of $\tilde{\rho}$.[27] I use observables from 2017 to estimate these parameters

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[25] 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

[26] 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.

[27] 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,

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 7: 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 7, 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.

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.

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containerized imports, and containerized exports between the US and that respective trade partner.

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 8, 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.

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

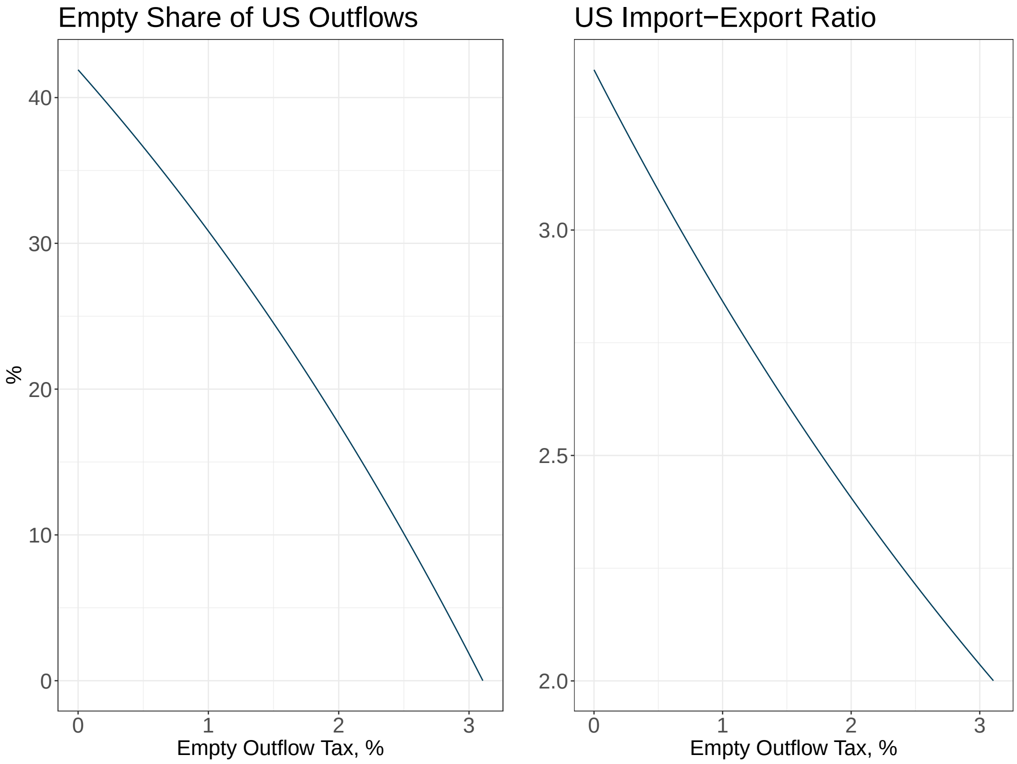
Table 8: National Counterfactual Outcomes

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%

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 12). 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 11: 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.

V. Loading Factor Estimates

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 12, 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 9: 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 10: 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.

Table 11: 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 12: 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

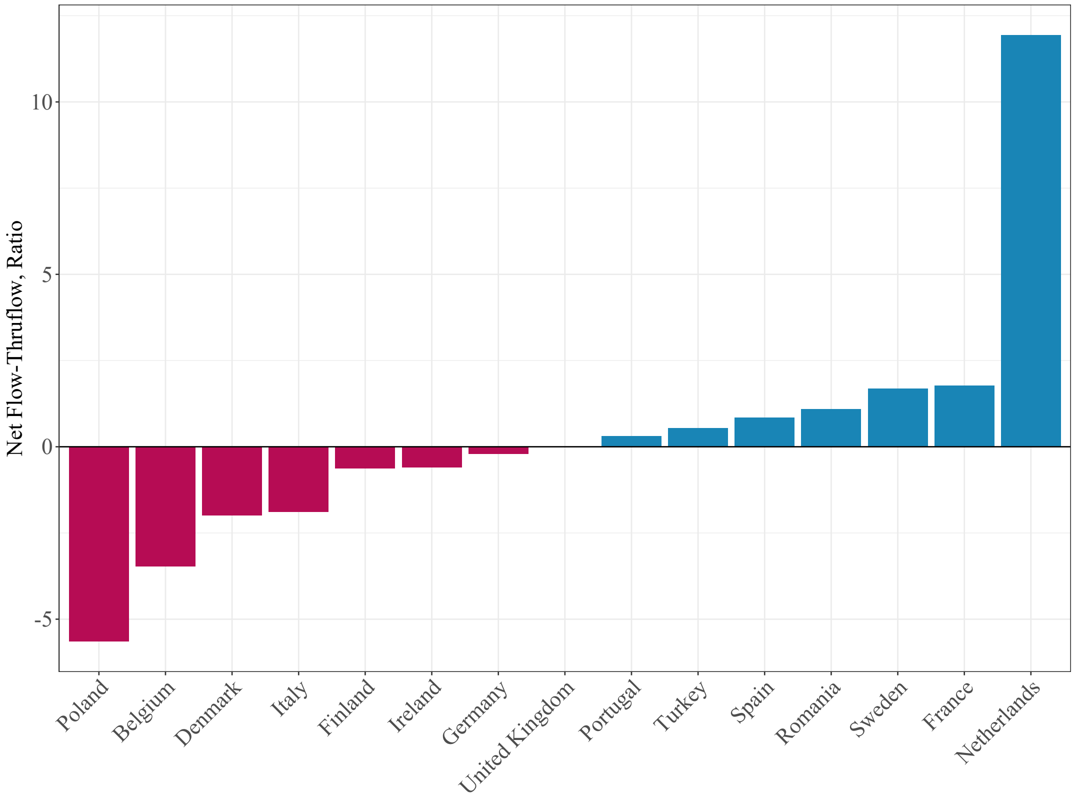
Note: The method list indicates which set of commodities were used as regressors in the estimation of commodity-specific loading factors. 'Full' uses the entire set of HS2 product types. 'Intersect' uses a subset of HS2 products that represent the top 50 highest commodity-specific shares of total export 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.

VI. The European Customs Union and Container Flows

Many of the countries featured in the multi-country baseline scenario of this paper are European. Of those countries, Austria, the Czech Republic, Hungary and Switzerland represent inland regions which could only be accessed by US containerized trade via third party coastal channels such as the ports of the Netherlands or Belgium. Each of these countries also maintains open access to the European Customs Union, which involves the free flow of goods, labor and capital. Due to the frictionless nature of trade and apparent interdependence of countries with respect to port access, I treat the EU Single Market as a single trade partner entity.

Eurostat container flow data suggests that only upon cross-country aggregation does the European Customs Union region function as a balanced container redistribution system. In contrast, individual European countries which form this union maintain imbalanced container flow systems at the national level.

Figure 12: European Specialization by Net Flow Status (2017)



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

VII. 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 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:

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

Consider a conventional MRTS in a transport setting, where capital K and labour 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.[28] This yields variation in the input price ratio

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[28] 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 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,

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.

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

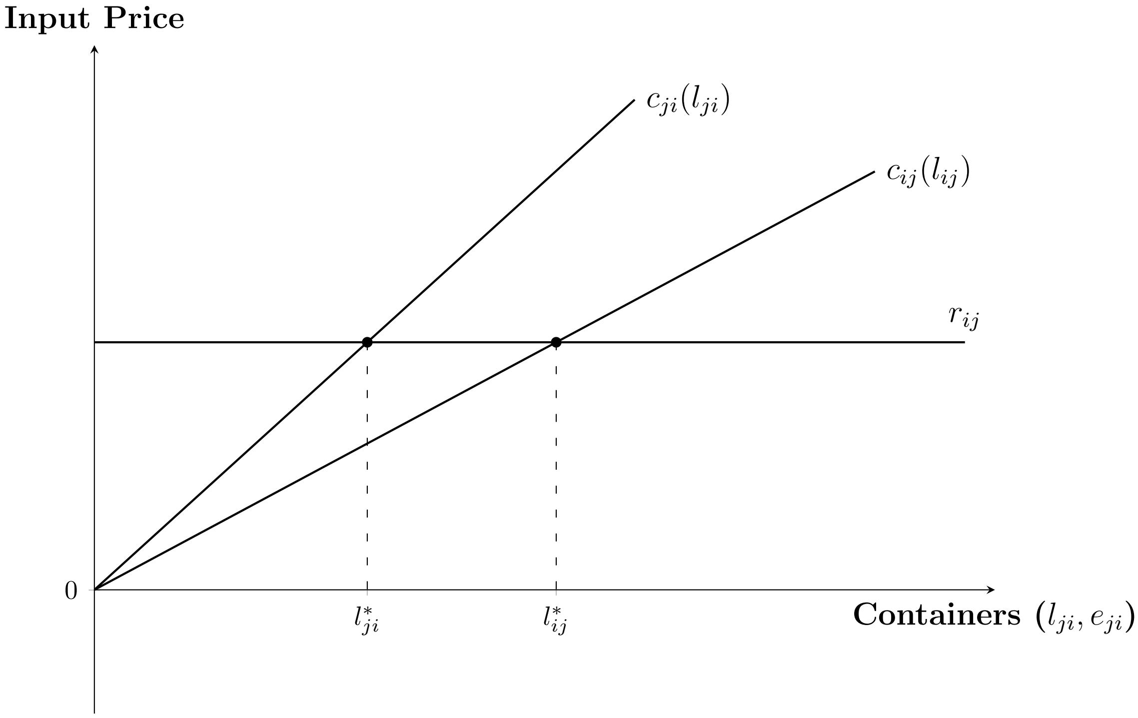
There are a number of ways of introducing this increasing input cost parameter. I resort to using the simplest possible expressions, where loaded container input prices increase linearly with respective quantities.

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.

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

Figure 13: Input Price by Loaded Container



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: $c_{ji}(l_{ji}) = \theta_{ij} l_{ji}$
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:

$$\begin{aligned}
&\max_{\{l_{ij}\}} \ \pi_{\overset{\leftrightarrow}{ij}} = T_{ij}l_{ij} + T_{ji}l_{ij} - (\theta_{ij}l_{ij})l_{ij} - (\theta_{ji}l_{ij})l_{ij} \\
&\text{FOC: } \frac{\partial \pi}{\partial l_{ij}} = 0 \implies T_{ij} + T_{ji} = 2\theta_{ij}l_{ij} + 2\theta_{ji}l_{ij} \\
&l_{ij} = l_{ji} = \frac{T_{ij} + T_{ji}}{2(\theta_{ij} + \theta_{ji})} \qquad (25)
\end{aligned}$$

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},

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

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.

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

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

$$l^*_{ij} = l^*_{ji} = \frac{T_{ij} + T_{ji}}{2(\theta_{ij}T_{ij} + \theta_{ji}T_{ji})} \tag{26}$$

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:

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

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

FOC:

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

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

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

$$l^S_{ij} = \frac{T_{ij} + r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ji}} \ , \ l^S_{ji} = \frac{T_{ji} - r_{\overset{\leftrightarrow}{ij}}}{2\theta_{ij}} \ , \ T^S_{ij} = 2\theta_{ji}l_{ij} + r_{\overset{\leftrightarrow}{ij}} \ , \ T^S_{ji} = 2\theta_{ij}l_{ji} - r_{\overset{\leftrightarrow}{ij}}$$

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

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

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:

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

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

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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