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The Round Trip Effect: Endogenous Transport Costs and International Trade†

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Container ships travel between a fixed set of origins and destinations in round trips, inducing a negative correlation in their freight rates. I study the implications of this round trip effect on international trade and trade policy. I identify this effect and develop an instrument using it to estimate the impact of transport costs on trade. I simulate counterfactual import tariff increases in a quantitative model and quantify the importance of endogenizing transport costs with respect to this effect: an exogenous transport costs model predicts a trade balance improvement from protectionist policies, while the round trip model finds the opposite. (*JEL* D22, F13, F14, L92, R41)

> If transport costs varied with volume of trade, the [iceberg transport costs] would not be constants. Realistically, since there are joint costs of a round trip, [the going and return iceberg costs] will tend to move in opposite directions, depending upon the strengths of demands for east and west transport.
>
> —Samuelson (1954, 270, fn. 2)

Cargo ships and containers typically go back and forth between a fixed set of origins and destinations in round trips (Pigou and Taussig 1913; Demirel, Van Ommeren, and Rietveld 2010).[1] This is an optimal strategy due to technological constraints and is well established in the transportation literature.[2] As a result, joint transportation costs are introduced, which link transport supply between these

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[1] One example is the US–China route currently serviced by Maersk, the largest container ship company globally, where ships travel exclusively between Yantian and Ningbo to Long Beach and back (Maersk East–West Network, TP3 Service).

[2] One contributing reason for this is the significant increase in container ship sizes (World Shipping Council 2017a). Larger ships spend longer times at port, which has decreased their average number of port calls per route. The number of port calls per round trip loop on the Far East–North Europe trade has decreased from five ports of call in 1989 down to three in 2009 (Ducruet and Notteboom 2012).

locations and induce a negative correlation in their freight rates, as acknowledged by Samuelson (1954). This is not just unique to container shipping; it also applies to air freight and trucking.[3]

This paper studies this feature of the transportation sector, termed the *round trip effect*, and its implications for international trade and trade policy. The round trip effect is defined as a phenomenon where exogenously driven shocks to transport quantity from i to j in turn affect the transport price from j to i. Consider a negative exogenous shock to transport demand from i to j, for example, due to an import tariff imposed by j on i. Transport quantity on this route would decrease. Due to ships going in a round trip between i and j, transport quantity from j to i decreases as well. This increases the transport price from j to i, which reduces its resultant trade. I refer to this as the spillover, or backfiring, consequence from the round trip effect. Additionally, this negative shock is partially mitigated by an endogenous decrease in the transport price from i to j since there is now less demand on this route. I refer to this as the mitigation consequence from the round trip effect.[4]

The first contribution in this paper is to identify the round trip effect empirically. While the existence of the round trip effect is widely accepted in the transportation literature, it has not been systematically documented due to lack of detailed data. This paper introduces a novel port-level freight rates dataset with a high level of disaggregation, which is able to address this issue. The main implication of the round trip effect, as predicted by my theoretical model and Samuelson (1954), is a negative correlation in freight rates between the same set of ports. To the best of my knowledge, this is the first paper to provide systematic evidence for this negative correlation. Since trade and freight rates on the same route are negatively correlated, I show that the round trip effect induces a positive correlation between freight rates and opposite-direction trade flows. To address the endogeneity between freight rates and trade flows, I construct a novel IV using the round trip insight to establish the impact of the round trip effect on freight rates. I introduce my IV below.

The second contribution in this paper uses the round trip effect to estimate a containerized trade elasticity with respect to transport price. Since containers are required to transport containerized trade, this elasticity can also be interpreted as the demand elasticity for containers. As in typical demand estimations, I require a transport supply shifter that is independent of demand determinants. The intuition for the supply shifter I utilize is as follows: due to the round trip effect, demand shocks to trade from United States to China will shift transport supply in both the original (US–China) and opposite (China–US) directions. The latter transport supply shift will identify the US demand for Chinese goods if the demand shocks between the routes are uncorrelated. Since demand shifts between countries are generally not independent, I construct a shift-share instrument that approximates this transport

[3] Air cargo costs 10 times more from China to the United States than the return (\$3–\$3.50/kilogram (kg) compared to \$0.30–\$0.40/kg back; Behrens and Picard 2011). US truck rentals cost 2 times more from Chicago to Philadelphia than the return (\$1,963 at \$2.69/mile compared to \$993 at \$1.31/mile back; see DAT Solutions 2011).

[4] The round trip effect is related to the backhaul problem but not solely a consequence of it. The backhaul problem is defined as the optimal adjustment of freight routes and pricing to avoid sending empty containers on the route with the lower demand (the backhaul route). See Section III for further discussion.

supply shift (Bartik 1991). I find that a 1 percent increase in container freight rates leads to a 2.8 percent decrease in containerized trade value, a 3.6 percent decrease in trade weight, and a 0.8 percent increase in trade value per weight.

The third contribution is to simulate counterfactual import tariff changes in a quantitative Armington trade model in order to evaluate the implications of this effect for trade policy. I show the broader economic importance of the round trip effect by quantifying the difference between the trade predictions from this model and a model that assumes that transport costs are exogenous. Additionally, I decompose the round trip effect into mitigation and backfiring effects. This paper simulates two trade policy counterfactuals, the impact of the United States doubling its import tariffs on its trading partners and the impact of the Trump administration's Section 301 tariffs on China. Using the latter counterfactual as an example, I show that an increase in US tariffs on China would decrease not just US imports from China (the magnitude of which is mitigated by a fall in US import transport costs from China—the mitigation effect), but also US exports *to* China. This export decrease is due to the overall fall in transport supply on the round trip route between the United States and China driven by the decrease in US imports—the spillover effect. A model assuming exogenous transport costs would overpredict the import decline by 30–35 percent relative to the round trip model and not predict any decrease in US exports. This results in the exogenous transport costs model predicting a trade balance improvement from protectionist policies while the round trip model finds the opposite.

This paper contributes to several strands of literature. First, it is broadly related to the literature that studies how trade costs affect trade flows between countries (Anderson and Van Wincoop 2004; Eaton and Kortum 2002; Head and Mayer 2014). In particular, this paper is related to the literature on endogenous transport costs (Allen and Arkolakis 2019; Hummels 2007; Limão and Venables 2001).[5] Focusing on dry bulk ships, Brancaccio, Kalouptsidi and Papageorgiou (2020) studies endogenous transport costs in the presence of search frictions between exporters and transport firms. This paper focuses on container ships, which have a different technology than dry bulk ships—container ships travel in fixed round trip routes like buses, while dry bulk ships do not and act more like taxis.[6] This paper contributes to this literature by investigating a new source of transport cost endogeneity—the round trip effect—and its implications for trade and trade policy. In addition to treating transport cost as an equilibrium outcome jointly determined with trade flows, transport costs are also simultaneously determined within routes as a result of the round trip effect.

Additionally, this paper is related to the literature on the round trip effect. Previous empirical studies on the round trip effect typically employ aggregated datasets, either at the regional level (Friedt and Wilson 2020) or within a country

[5] Behrens, Brown, and Bougna (2018) and Behrens and Brown (2018) study the impact of endogenous transport costs on geographic concentration, while Asturias (2020); Francois and Wooton (2001); and Hummels, Lugovskyy, and Skiba (2009) focus on market power within the transport sector.

[6] Dry bulk ships are likely to depart from their destinations without cargo and therefore have to search for their next load, while container ships have fixed publicized schedules since they are able to pick up a wide variety of cargo at each stop.

at the annual frequency (Tanaka and Tsubota 2017; Jonkeren et al. 2011).[7] As such, these papers have not been able to convincingly establish the presence of the round trip effect empirically. The dataset in this paper is highly disaggregated at the monthly frequency and the port level in both directions, and it includes all the largest ports globally.[8] Since container ships only take a few weeks to complete a round trip each time, it is important for my dataset to have this rich level of detail in order to capture the freight rate variation between routes. This high level of disaggregation allows me to contribute to this literature by providing empirical evidence for the round trip effect as well as highlighting its trade implications. I am also able to exploit the panel nature of this dataset in my empirical estimations to control for confounding factors.[9]

Relative to studies on trade elasticities, this paper contributes by estimating a short-run trade elasticity at the port level for containerized goods. This trade elasticity also takes into account endogeneity concerns between trade and trade costs. While there are important exceptions,[10] transport costs are generally modeled as exogenous, approximated by distance empirically and by the iceberg functional form theoretically. I develop a novel instrument based on the institutional details of the transportation industry in order to causally identify the elasticity of containerized trade with respect to transport price. In addition, previous studies have focused on trade elasticities at the country level and across all transport modes. My elasticity contributes to understanding how trade responds to transport cost changes at the port level and within a mode, i.e., container shipping. Port-level trade elasticities are not often estimated due to data limitations (one recent exception being Asturias 2020). Short-term elastiticities, especially at the monthly level, are also rarely estimated in the literature (one exception being Fajgelbaum et al. 2019). My elasticity can shed light on how trade adjusts, taking into account substitution across ports and over the short run. Additionally, I contribute to studies on product-level trade elasticities by estimating a trade elasticity for containerized goods (Caliendo and Parro 2015; Shapiro 2016; Steinwender 2018).

This paper also contributes to studies on the trade policy implications from the round trip effect. Ishikawa and Tarui (2018) is an applied theory paper that shows that trade policy changes in the presence of the backhaul problem can lead to a backfiring problem—increases in a country's import tariffs on its partner can lead to a decrease in its exports to the same partner. My paper empirically identifies the underlying mechanism that leads to this backfiring problem (the negative correlation in freight rates), shows that it is not solely a consequence of routes with trade imbalance (i.e., routes that face the backhaul problem), and decomposes the

[7] Tanaka and Tsubota (2017) estimates the effects of trade flow imbalance on transport price ratio between Japanese prefectures. Focusing on three regions (North America, Asia, and Europe), Friedt and Wilson (2020) evaluates the impact of freight rates on dominant and secondary routes. Jonkeren et al. (2011) focuses on dry bulk cargo in the inland waterways of the Rhine. Friedt (2017) studies the impact of commercial and environmental policy on US–EU bilateral trade flows in the presence of the round trip effect.

[8] This dataset includes the majority of the world's leading container ports, but not all operating ports.

[9] This includes addressing the orthogonality conditions for shift-share instruments (Borusyak, Hull, and Jaravel 2022).

[10] Important exceptions include Allen and Arkolakis (2019); Donaldson (2018); Asturias (2020); Hummels, Lugovskyy, and Skiba (2009); and Irarrazabal, Moxnes and Opromolla (2015).

round trip effect into the mitigation effect and the backfiring effect in a quantitative model. With aggregate Organisation for Economic Co-operation and Development (OECD) data, Hayakawa, Ishikawa and Tarui (2020) tests the theoretical predictions in Ishikawa and Tarui (2018) by estimating the effect of import tariffs on exports using dry bulk product tariffs as an instrument for containerized product tariffs. They interpret the round trip effect as the underlying mechanism that is driving their results. Using more detailed data, my paper provides direct empirical evidence of the round trip effect. I also show the broader economic importance of the round trip effect by quantifying the trade prediction differences between this model and a model that assumes that transport cost is exogenous.

Last but not least, the existing literature on container technology and trade have studied the impact of containerization on trade and on substitution with other modes of transport (Bernhofen, El-Sahli and Kneller 2016; Coşar and Demir 2018; Rua 2014). This paper contributes by highlighting the trade and trade policy implications from the round trip effect, which is a key feature of the container transport network structure.

In the next section I present my theoretical framework and establish theoretical predictions on the round trip effect and its implications on international trade. Section II introduces my data. I introduce two stylized facts in Section III that affirm my theoretical predictions and identify the impact of the round trip effect on transport prices using an instrument based on the round trip effect insight. Section IV uses the instrument to estimate a trade elasticity. In Section V, I utilize the trade elasticity from Section IV to estimate parameters in the model from Section I in order to simulate two counterfactuals—a doubling of US import tariffs on its trading partners and the impact of the Trump administration's section 301 tariffs on China. Section VI concludes.

I. Theoretical Framework

This section presents the theoretical implications of endogenous transport costs and the round trip effect. Since the round trip effect is a general phenomenon that can come out of a variety of models, the simplest possible approach is chosen here. To highlight the trade implications of the round trip effect, my results are discussed in comparison to a model where transport costs are assumed to be exogenous (see online Appendix A.C).[11]

A. *Model Setup*

The model in this paper extends Hummels, Lugovskyy and Skiba (2009) to incorporate the round trip effect, based on Behrens and Picard (2011), and to allow for heterogeneous countries. The world consists of M potentially heterogeneous countries, where each country produces a different variety of a tradeable good. Consumers consume all varieties of this tradeable good from all countries as well

[11] Online Appendix Figure A.1 presents a graphical illustration of the round trip effect, assuming linear demand and supply transport markets (further details in online Appendix B.B).

as a homogeneous numeraire good. The transport firms transport the tradeable goods from producer countries to consumers.

The utility function of a representative consumer in country j is quasilinear:

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

where q_{j0} is the quantity of the numeraire good consumed by country j, a_{ij} is j's preference parameter for the variety from country i, q_{ij} is the quantity of variety from i consumed in j, and ϵ is the price elasticity of demand. The numeraire good is costlessly traded, and its price is normalized to one.

Each country is perfectly competitive in producing their variety, and labor is the only input to production. As such, the delivered price of country i's good in j (p_{ij}) reflects its delivered cost, which is increasing in i's domestic wages (w_i), the ad valorem tariff rate that j imposes on i $(\tau_{ij} \geq 1)$, and the per unit transport cost from i to j (T_{ij}):

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

The profit function of a perfectly competitive transport firm servicing the round trip between i and j $(\pi_{ij}^{\leftrightarrow})$ is as below (Behrens and Picard 2011):

$$\pi_{ij}^{\leftrightarrow} = T_{ij} q_{ij} + T_{ji} q_{ji} - c_{ij}^{\leftrightarrow} \max\{q_{ij}, q_{ji}\}, \tag{3}$$

where q_{ij} is the quantity of goods shipped from i to j, while $c_{ij}^{\leftrightarrow}$ is the marginal cost of serving the round trip between i and j, like the cost of hiring a crew or renting a ship, both of which would increase with quantity. While this cost function does not include one-way expenses like loading or unloading costs and fuel, the main results would be robust to including them. Following Behrens and Picard (2011) and Hummels, Lugovskyy, and Skiba (2009), one unit of transport services is required to ship one unit of good.

While the perfect competition assumption here is mostly to maintain simplicity, a number of recent factors, including procompetitive policies implemented by the Federal Maritime Comission, contribute to the basis for this assumption.[12] Moreover, as discussed later on, the main results do not hinge on this assumption.

B. *Equilibrium Conditions*

As in Behrens and Picard (2011), I find two possible equilibrium outcomes from this model, depending on the relative demand between countries. The first equilibrium is an interior solution where the transport market is able to clear at positive freight rates in both directions and the quantity of transport services are balanced

[12] Additional factors include the surplus of capacity documented by the 2013 Review of Maritime Transport (UNCTAD) due to the 2008 recession and time to build lags (Kalouptsidi 2014). Jeon (2017), which studies how demand uncertainty affects investment and welfare in the container shipping industry, finds that this industry is relatively unconcentrated based on the Herfindahl index (less than 1,000).

between the countries. The second equilibrium is a corner solution where one market is able to clear at positive freight rates, while the opposite-direction market has an excess supply of transport firms. The transport freight rate of the excess supply direction is zero. Nonzero freight rates in the data suggest that the first equilibrium is more relevant, and hence, is the focus here. However, the main results are robust to relaxing this balanced quantity assumption with a search framework (see online Appendix B.E).

From the transport firm's profit function in (3), the optimal freight rates on routes ij and ji will add up to equal the marginal cost of the round trip between i and j:

$$T_{ij} + T_{ji} = c_{ij}^{\leftrightarrow}, \tag{4}$$

which implies that the freight rates between i and j are negatively correlated with each other conditional on the round trip marginal cost $c_{ij}^{\leftrightarrow}$. This negative relationship is affirmed in the first stylized fact in Section III (Figure 1).

From utility-maximizing consumers in (1) and profit-maximizing manufacturing firms in (2), the optimal trade value of country i's good in j is given by

$$X_{ij} = \left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(w_i\tau_{ij} + T_{ij}\right)^{1-\epsilon}, \quad \epsilon > 1. \tag{5}$$

It is decreasing in wages in i, j's import tariffs on i, and the transport cost from i to j. This negative relationship between trade value and transport cost is empirically confirmed in my data (see online Appendix Table A.2).

Combining both equations (4) and (5), we can see that the trade value of country i's good in j is positively correlated with the return-direction freight rates from j to i. This positive relationship is affirmed in the second stylized fact in Section III (Figure 2):

$$X_{ij} = \left(\frac{\epsilon}{\epsilon - 1}\frac{1}{a_{ij}}\right)^{-\epsilon}\left(w_i\tau_{ij} + c_{i,j} - T_{ji}\right)^{1-\epsilon}, \quad \epsilon > 1. \tag{6}$$

The equilibrium freight rate for route ij under the round trip effect (T_{ij}^R) can be derived from the market-clearing condition for transport services:

$$T_{ij}^R = \frac{1}{1 + A_{ij}}\left(c_{ij}^{\leftrightarrow}\right) - \frac{1}{1 + A_{ij}^{-1}}\left(w_i\tau_{ij}\right) + \frac{1}{1 + A_{ij}}\left(w_j\tau_{ji}\right), \quad A_{ij} = \frac{a_{ji}}{a_{ij}}, \tag{7}$$

where A_{ij} is the ratio of preference parameters between i and j. The first term shows that the freight rate from i to j is increasing in the marginal cost of servicing the round trip route $(c_{ij}^{\leftrightarrow})$. The second term shows that it is decreasing with the destination country j's import tariff on i (τ_{ij}) and origin i's wages (w_i). The third term, due to the round trip effect, shows that the freight rate is increasing in the origin country i's import tariff on j (τ_{ji}) as well as destination j's wages (w_j). The second term is the mitigating effect on the changes in trade demand or supply on route ij, while the third term is the spillover effect from changes on the opposite route ji.

The equilibrium price of country i's good in j is increasing in the marginal cost of round trip transport $c_{ij}^{\leftrightarrow}$ as well as the wages and import tariffs in both countries.

This price is a function of j's own wages and the import tariff that it faces from i, which is due to the round trip effect:

$$(8) \qquad p_{ij}^{R} = \frac{1}{1+A_{ij}}\left(w_j\tau_{ji} + w_i\tau_{ij} + c_{ij}^{\leftrightarrow}\right), \quad A_{ij} = \frac{a_{ji}}{a_{ij}}.$$

The equilibrium trade quantity and value on route ij are decreasing in the marginal cost of transport, both countries' wages, and import tariffs:[13]

$$(9) \qquad q_{ij}^{R} = \left[\frac{\epsilon}{\epsilon-1}\,\frac{1}{a_{ij}}\,\frac{1}{1+A_{ij}}\left(w_j\tau_{ji} + w_i\tau_{ij} + c_{ij}^{\leftrightarrow}\right)\right]^{-\epsilon}$$

$$X_{ij}^{R} = \left[\frac{\epsilon}{\epsilon-1}\,\frac{1}{a_{ij}}\right]^{-\epsilon}\left[\frac{1}{1+A_{ij}}\left(w_j\tau_{ji} + w_i\tau_{ij} + c_{ij}^{\leftrightarrow}\right)\right]^{1-\epsilon}, \quad A_{ij} = \frac{a_{ji}}{a_{ij}}.$$

These equilibrium outcomes are due to the round trip effect: a country's imports and exports to a particular trading partner are linked through transportation. For example, when country j increases its import tariff on country i (τ_{ij}), not only will its own imports from i be affected, but its exports to i will be as well.

C. *Comparative Statics*

This subsection describes the trade predictions from changes in import tariffs and preferences between this model and a model with exogenous transport costs (see online Appendix A.C).

When country j's import tariff on country i (τ_{ij}) increases, an exogenous transport cost model will only predict changes in j's imports from i. The price of j's imports from i will become more expensive (equation (A.1)), while its import quantity and value from i will fall (equation (A.2)). There will be no changes on the exports side.

When transportation is endogenized to take into account the round trip effect, however, j's import tariff increase will affect both j's imports from and its exports to i. This is due to the endogenous response from j's import and export freight rates to i. First, country j's import freight rate will fall to mitigate the impact of the tariff (equation (7)). This decrease is not enough to offset j's net import price increase from i (equation (8)), which results in a fall in j's import quantity and value (equation (9)). This import fall, however, is less than the import fall in the exogenous model.

Second, the impact of j's import tariff on i will spill over to j's exports to i due to the round trip effect. The fall in imports from i to j decreases transport services on route ij, which translates into a decrease in transport services in the opposite direction from j to i. All else equal, a fall in transport quantity from j to i due to the round trip effect results in an increase in j's export freight rate to i (equation (7)).

[13] If countries are symmetric (i.e., have symmetric preferences $a_{ij} = a_{ji}$), the freight rates each way will be half the marginal cost: $T_{ij}^{Sym} = T_{ji}^{Sym} = (1/2)\,c_{ij}^{\leftrightarrow}$, and the countries will face the same prices, quantities, and values. See online Appendix A.C for more details.

Country *j*'s export price to *i* increases from the export freight rate increase, while its export quantity and value to *i* fall (equations (8) and (9)). The following lemma can be shown (see online Appendix B.D for proof):

LEMMA 1: *When transport costs are assumed to be exogenous, an increase in the origin country j's import tariffs on its trading partner i's goods only affects its imports from its partner. Its import price from its partner will rise, while its import quantity and value will fall.*

$$\frac{\partial p_{ij}^{Exo}}{\partial \tau_{ij}} > 0, \quad \frac{\partial q_{ij}^{Exo}}{\partial \tau_{ij}} < 0, \quad \textit{and} \quad \frac{\partial X_{ij}^{Exo}}{\partial \tau_{ij}} < 0.$$

When transport costs are endogenous and determined on a round trip basis, this import tariff increase will affect both the origin country's imports and its exports to its partner. On the import side, the origin country's import freight rate falls in addition to the effects under the exogenous model. The import quantity and value decrease is larger under the exogenous model.

$$\frac{\partial T_{ij}^{R}}{\partial \tau_{ij}} < 0, \quad \frac{\partial p_{ij}^{R}}{\partial \tau_{ij}} > 0, \quad \frac{\partial q_{ij}^{R}}{\partial \tau_{ij}} < 0, \quad \frac{\partial X_{ij}^{R}}{\partial \tau_{ij}} < 0, \quad \frac{\left|\partial X_{ij}^{Exo}/\partial \tau_{ij}\right|}{\left|\partial X_{ij}^{R}/\partial \tau_{ij}\right|} > 0,$$

and

$$\frac{\left|\partial X_{ij}^{Exo}/\partial \tau_{ij}\right|}{\left|\partial X_{ij}^{R}/\partial \tau_{ij}\right|} > 0.$$

On the export side, the exogenous trade model does not predict any changes. However, the endogenous model predicts a rise in the origin country's export freight rate and price to its partner, while its export quantity and value decrease.

$$\frac{\partial T_{ji}^{R}}{\partial \tau_{ij}} > 0, \quad \frac{\partial p_{ji}^{R}}{\partial \tau_{ij}} > 0, \quad \frac{\partial q_{ji}^{R}}{\partial \tau_{ij}} < 0, \quad \textit{and} \quad \frac{\partial X_{ji}^{R}}{\partial \tau_{ij}} < 0.$$

Similar results can be derived for changes in a country's preferences (see online Appendix A.C). In general, there are two main differences between the round trip model and the model with exogenous transport costs. The first is that the transport costs in the round trip model mitigate the effects of underlying changes in trade demand and supply, like tariffs and preferences. This first point can be generated in a transport model with rising costs. However, since the transport industry here is assumed to be perfectly competitive with constant costs, this prediction is solely generated by the round trip effect.

The second difference is that any demand or supply trade changes for a country will have spillover effects on its opposite-direction trade with the same partner. In the case of Lemma 1, an import tariff will therefore also translate into an export tax. The following proposition can be stated.

PROPOSITION 1: *Under the assumption of competitive transport firms*,

(*i*) *When transport costs are endogenous and determined on a round trip basis under the interior solution equilibrium*, *increases in import tariffs* τ_{ij} *decrease both equilibrium imports from and exports to the same partner*: $\frac{\partial X_{ij}^{R}}{\partial \tau_{ij}} < 0$ *and* $\frac{\partial X_{ji}^{R}}{\partial \tau_{ij}} < 0$.

(*ii*) *When transport costs are endogenous and determined on a round trip basis under the interior solution equilibrium*, *an increase in preference shock* a_{ij} *increases both equilibrium imports from and exports to the same partner*: $\frac{\partial X_{ij}^{R}}{\partial a_{ij}} > 0$ *and* $\frac{\partial X_{ji}^{R}}{\partial a_{ij}} > 0$.

(*iii*) *When transport costs are exogenous, there are only changes in imports and no corresponding changes in exports*: $\frac{\partial X_{ij}^{Exo}}{\partial \tau_{ij}} < 0$, $\frac{\partial X_{ji}^{Exo}}{\partial \tau_{ij}} = 0$, $\frac{\partial X_{ij}^{Exo}}{\partial a_{ij}} < 0$, *and* $\frac{\partial X_{ji}^{Exo}}{\partial a_{ij}} = 0$.

(*iv*) *The relative import changes are larger from import tariffs or preference changes when transport costs are exogenous*: $\frac{|\partial X_{ij}^{Exo}/\partial \tau_{ij}|}{|\partial X_{ij}^{R}/\partial \tau_{ij}|} > 0$ *and* $\frac{|\partial X_{ij}^{Exo}/\partial a_{ij}|}{|\partial X_{ij}^{R}/\partial a_{ij}|} > 0$.

The main results above are robust and continue to hold when the key assumption—balanced quantity—is relaxed. I show this by extending Chaney (2008) to include the round trip effect and a search framework between transport firms and exporting firms, which allows for container ships to be at less than full capacity on either legs of a route (Miao 2006). As a result, I can relax the assumption that transport quantities have to be the same (see online Appendix B.E for further details). In order to export, manufacturing firms will need to successfully find a transport firm and negotiate a transport price. This operation matches the fact that there are long-term contracts in container shipping that are negotiated, which can provide more favorable terms to an exporter who can commit to moving a steady stream of goods over time—a larger or more productive exporter. This search process also smooths the relationship between price and quantity relative to the trade shocks, which renders the balanced quantity assumption unnecessary. Given this framework, the main spillover predictions continue to hold (Proposition 3, online Appendix B.E). When allowing for imperfect competition, the main mitigating and spillover results continue to hold. However, these effects could be larger or small, depending on whether the demand specification's pass-through is greater or less than 1 (Proposition 2, online Appendix A.D).

In addition, Ishikawa and Tarui (2018) is an applied theory paper that finds the same spillover results with an oligopolistic transportation model. Focusing on intermediate goods, Mostashari (2011) finds evidence broadly consistent with the bilateral export impact of a country's import tariff, as I do with the round trip effect. Unilateral import tariff cuts by developing countries can contribute to their bilateral exports to the United States since these tariff cuts reduce the cost of their imported intermediate goods, which makes their exports, using these intermediate goods, relatively more competitive.

Lerner (1936) symmetry predicts that a country's unilateral tariff increase on one partner will act as an export tax and reduce its exports to all its partners due to the balanced trade condition in a general equilibrium setting. I highlight a specific *bilateral* channel that impacts the country's exports to the same partner within a partial equilibrium framework without requiring the balanced trade condition. These findings are in line with Costinot and Werning (2019), which shows that trade balance is not a necessary or sufficient condition for the Lerner (1936) symmetry to hold.

II. Data

Container shipping is a six-trillion-dollar industry that is responsible for transporting more than 95 percent of the world's manufactured goods (Wall Street Journal 2015) and two-thirds of total world trade by value (World Shipping Council 2017b). In the United States, container shipping accounts for almost two-thirds of vessel trade in 2017.

A. *Background*

Drewry Maritime Research (2011–2016)—henceforth, "Drewry"—compiles monthly port-level container freight rate data from importer and exporter firms located globally.[14] This novel dataset, to the best of my knowledge, is the only source of container freight rates on major global routes. These ports are the largest globally, handling more than one million containers annually, and they are a subset of all operating container ports. Container cargo handling is very concentrated at major ports, where the combined container traffic at the world's top 20 container ports accounts for about 50 percent of the world's total (UNCTAD 2011). My dataset covers 12 of these 20 ports, accounting for a majority of the world's leading container ports.

The high level of disaggregation in this dataset—at the monthly and port level—has three main benefits. First, it can shed light on our understanding of how freight rates vary across these major global routes and across relatively high frequency. The fact that the Drewry dataset is based on actually paid freight rates is very valuable since there are other freight rate sources that artificially generate part of their freight rate data from algorithms.[15] Second, this detailed dataset allows for the first contribution of the paper—the empirical identification of the round trip effect. Previous papers have relied on much more aggregated data and are not able to convincingly establish the presence of the round trip effect. Third, this high degree of disaggregation allows me to utilize the round trip effect as a novel IV strategy to estimate a short-run trade elasticity with respect to transport costs—the second contribution of this paper. I am also able to exploit the panel nature of this data in my empirical estimations to control for confounding factors.

[14] Many thanks to Nidhin Raj, Stijn Rubens, and Robert Zamora at Drewry for their help. These freight rates represent the lower bound of total transport costs since they do not include the cost of inland transport.

[15] One example is worldfreightrates.com.

These freight rates are spot market rates for a standard 20-foot container. While spot market and longer-term contract rates are both present in container markets, I choose to focus on spot market rates for two main reasons. The first is data availability. Contract rates are filed confidentially with the Federal Maritime Commission and are protected against Freedom of Information Act requests. Second, persistent overcapacity during my sample period resulted in a variety of linkages between contract and spot rates. Both these reasons suggest that spot prices play a major role in informing longer-term contracts and are, to my knowledge, the best alternative currently available for shedding light on container transport markets as well as the the round trip effect (see online Appendix A.B for further details).

In order to compare apples to apples, I match my dataset to trade in containers. Monthly containerized US trade data at the port level comes from the Census Bureau's USA Trade Online (2011–2016) at the six-digit Harmonized System (HS) product code level.[16] It includes the trade value and weight between US ports and foreign partner countries.

For the United States, Drewry collects freight rate data on three of its largest container ports (Los Angeles/Long Beach, New York, and Houston). All combined, these ports handle 16.7 million containers annually—more than half of the annual US container volume (MARAD 2011–2015). Since my freight rate data are at the port-to-port level, I aggregate them to the US port–foreign country level to match the containerized trade data (online Appendix A.B elaborates). The level of observation in the combined dataset is at the US port–foreign partner country–product level. This combined dataset accounts for the majority of all US vessel trade and spans January 2011 to June 2016.[17] While these port pairs are the largest globally, this dataset covers a subset of all the ports globally—there are 21 foreign countries in this dataset.[18] This is a conservative estimate since Drewry has indicated that their freight rate data can be applied to adjacent ports.[19] Overall, the ports in this dataset are 21 of the largest foreign ports, handling more than 500 million tons of cargo volume annually, with at least 1 port per continent.

The combined data coverage includes the net freight rates, trade value, and trade weight to ship from i to j, regardless of whether it is a direct or indirect route. My freight rate data from Drewy are based on the actual rates paid by freight forwarders

[16] Containerized trade data are not readily available for all other countries apart from the United States, which limits my analysis to US trade in this paper. All data were converted into real terms using the seasonally adjusted Consumer Price Index for All Urban Consumers published by the Bureau of Labor Statistics.

[17] Shipping vessels that carry trade without containers include oil tankers, bulk carriers, and car carriers. Bulk carriers transport grains, coal, ore, and cement.

[18] The port pairs are between three US ports (New York, Houston, and Los Angeles/Long Beach) and the following ports: Australia (Melbourne), Brazil (Santos), China, Hong Kong, India (Nhava Sheva), Japan (Yokohama), Korea (Busan), Malaysia (Tanjung Pelepas), New Zealand (Auckland), North Continent Europe (Rotterdam), the Philippines (Manila), Russia (St. Petersburg), Singapore, South Africa (Durban), Taiwan (Kaohsiung), Thailand (Laem Chabang), Turkey (Istanbul), the United Arab Emirates (Jebel Ali), the United Kingdom (Felixstowe), Vietnam (Ho Chi Minh), and West Med (Genoa).

[19] Drewry made the strategic decision to collect one set of data on ports that are close together. Examples of these include Long Beach and Los Angeles as well as the ports surrounding Rotterdam. The reason for this, according to them, is because freight rates are similar across these ports. One example is the data for the port of Rotterdam. According to Drewry, this port represents the "Hamburg–Le Havre range," which means that its data are representative of the data for Antwerp (Belgium), Le Havre (France), Hamburg (Germany), Zeebrugge (Belgium), and Bremerhaven (Germany). However, I have not done this in order for the port matches to be accurate and to avoid the Rotterdam effect. As such, Belgium, France, and Germany are not in my dataset.

Table 1—Summary Statistics

	US exports	US imports	Full sample
Freight rate ($)	1,399	2,285	1,842
	(689)	(758)	(849)
Value (billion $)	0.117	0.422	0.27
	(0.21)	(1.8)	(1.3)
Weight (billion kg)	0.0521	0.0811	0.0666
	(0.13)	(0.33)	(0.25)
Value per weight	4.01	4.27	4.14
	(2.6)	(4.5)	(3.6)
Observations	2,842	2,842	5,684

Notes: Standard deviation in parentheses. Observations at the US port–foreign country level. There are 3 US ports and 21 foreign countries, but the Drewry freight rate data do not start at January 2011 for all routes. Imports exclude US import duties, freight, insurance, and other charges incurred in bringing the merchandise to the United States. Exports are valued on a free alongside ship basis.

Sources: Drewry, Census Bureau, and author's calculations

and companies to ocean carriers in order to ship their cargo between particular port pairs. Similarly, my trade data from the Census Bureau include coverage on merchandise shipped in transit through the United States from one foreign country to another, in addition to direct coverage on movement of merchandise between the United States and foreign countries.

As a result of capturing both direct and indirect routes, these data also include transshipments. This is to the extent that the port that these goods are moving through is a hub port. It is important to note, however, that the 21 foreign ports in this dataset are a mix of transshipment and large ports. While some of these ports are well-known transshipment hubs (like Singapore, Rotterdam, and Hong Kong), most of these ports are in relatively large trading countries (like the United Kingdom, Australia, and Russia), with some playing a role in both (like China).[20]

B. *Summary Statistics*

Table 1 presents the summary statistics for the matched dataset, which is broken down by US exports, US imports, and total US trade. These variables are, on average, higher for US imports than for US exports. While the higher import values and weight are not surprising since the United States is a net importer, freight rates are also higher for US imports than for US exports. The value per weight of US imports is also, on average, higher than that of US exports. These patterns are robust to using data on container volumes (see online Appendix Table A.11).

Between port pairs, the average gap in container freight rates between port pairs is 1.95, with wide variation (panel A, online Appendix Figure A.4). This shows that freight rates are not symmetric—entirely explained by distance or fixed bilateral

[20] Ganapati, Wong, and Ziv (2021) finds that both well-known hub ports and large trading countries have more direct trade with the United States. Direct trade can be measured in terms of the share of nontransshipped volume or the number of stops that a container ship makes before arriving at its destination.

characteristics—for the majority of port pairs. In fact, I find a link between asymmetric freight rates and asymmetric demand between locations. For example, China runs a large trade surplus with the United States, and the cost to ship a container from China to the United States ($1,900 per container) is more than 3 times the return cost ($600 per container; Drewry). The United States and the United Kingdom, who have relatively more balanced trade with each other, have more similar container costs ($1,300 per container from the United Kingdom to the United States compared to the return cost of $1,000 per container). Panel B shows this positive correlation: the gap in containerized trade value to and from a pair of countries, which approximates the trade demand asymmetry between countries, is positively correlated with the gap in the cost of containers going to and from these countries (see online Appendix Figure A.4). This positive relationship is also present using container volumes (see online Appendix Figure A.2).

III. Impact of the Round Trip Effect on Freight Rates

In this section I introduce two stylized facts that provide empirical evidence of the round trip effect based on my theoretical predictions. Next, since trade and freight rates are endogenously determined, I introduce an instrument based on the round trip insight to establish the impact of the round trip effect on freight rates.

A. *Stylized Facts*

STYLIZED FACT 1: *A positive deviation from the average freight rates from i to j is correlated with a negative deviation from the average opposite-direction freight rates from j to i.*

This inverse relationship, using just the freight rate dataset, is the result of regressing the freight rates between port pairs on each other, controlling for time trends and route characteristics.[21] Figure 1 presents a visual representation of this regression by regressing the freight rates on time and route fixed effects, collecting the residuals, and then graphing the T_{ijt} residuals on T_{jit} (its opposite-direction counterpart). Online Appendix Table A.1 presents the regression results.

I find that a 1 percent deviation from the average container freight rates from i to j is correlated across time with a negative deviation of 0.84 percent from the average container freight rates from j to i. This result is robust to using port distances instead of route fixed effects (column 1, online Appendix Table A.1). This result is also robust to restricting the sample to routes that are more balanced or imbalanced, with the imbalanced routes having a slightly higher negative correlation intuitively since the backhaul problem is relatively more severe for these routes (columns 3

[21] Route fixed effects, which are directional port-pair fixed effects, are included in the regression used to construct this figure. As such, this figure is identified from the time variation within routes. If the fixed effects were at the dyad, nondirectional level, then a mechanical negative correlation could arise. However, this is not the case here. See online Appendix Table A.1 for further details.

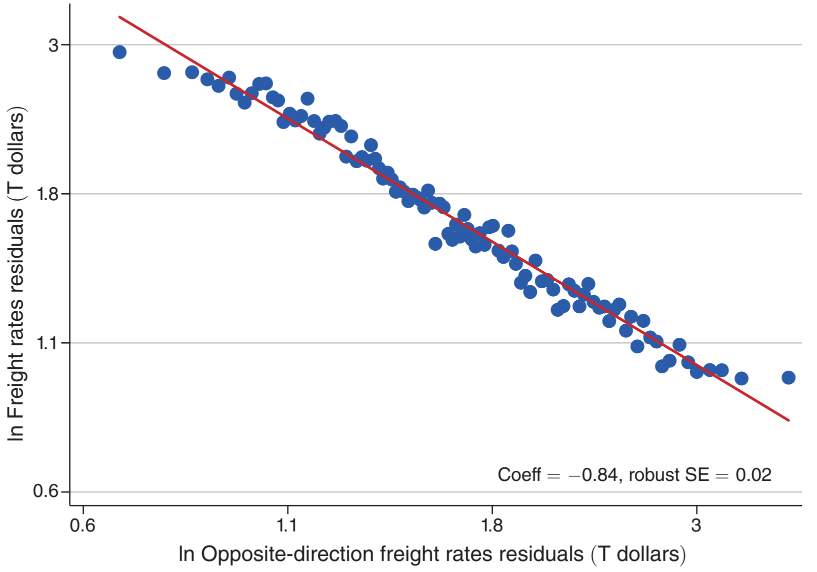

Figure 1. Residualized Plot of Correlation between Freight Rates within Port Pairs

Notes: Binned scatterplot with observation at the route–month level (3,210 observations). Robust standard errors clustered by route with time and route controls. The y-axis variable, ln Freight rates residuals, is defined as $\hat{\varepsilon}_{ijt} = \ln T_{ijt} - \hat{\gamma}_t - \hat{d}_{ij}$ where $\hat{\gamma}_t$ and $\hat{d}_{ij}$ are time- and route-level controls, respectively. The x-axis variable is its opposite-direction counterpart. Online Appendix Table A.1 presents the regression results.

Sources: Drewry and author's calculations

and 4, online Appendix Table A.1).[22] This latter result shows that the backhaul problem is a necessary but not sufficient condition for the round trip effect.

This negative relationship is not typically predicted in the trade literature. If freight rates can be approximated by distance and therefore are symmetric, as assumed in some of the literature, the route fixed effects would absorb all the variation in the data. If freight rates were exogenous, one might expect no correlation or a noisy estimate. In fact, as noted in the introduction, when Samuelson (1954) introduced the iceberg transport cost, he provided two caveats. First, if transport costs varied with trade volume, then transport costs would not be constant—as I show in online Appendix Figure A.4. Second, since, realistically, there are joint costs of a round trip for transportation, the going and return transport costs will tend to move in opposite directions depending on the demand levels—as I show in Figure 1.[23] I confirm both his caveats here.

This next stylized fact shows that a country's imports and exports with a particular partner are linked via their outgoing and return transport costs.

[22] More balanced routes are defined as routes that are in the second and third quartiles of the US trade imbalance distribution from the year 2003—at least eight years prior to the start of my data. More imbalanced routes are in the first and fourth quartiles of the distribution.

[23] The relationship in Figure 1 is not solely driven by systematic currents and wind conditions, since Chang et al. (2013) estimates only a modest amount of time savings (1 to 8 percent) when ships utilize strong currents or avoid unfavorable currents in the North Pacific.

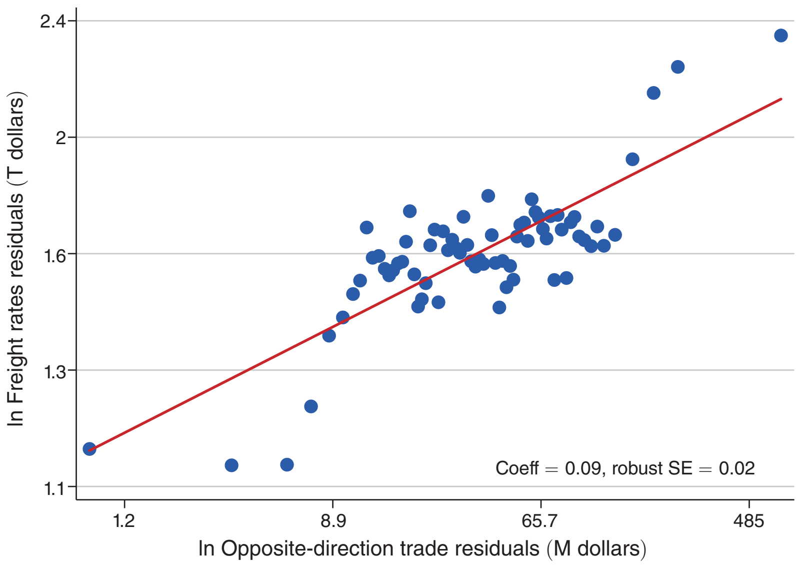

Figure 2. Residualized Plot of Correlation between Containerized Trade Value and Opposite-Direction Freight Rates

Notes: Binned scatterplot with observation at the route–month level (5,268 observations). Robust standard errors clustered by route with time and dyad controls. The *y*-axis variable, ln Freight rates residuals, is defined as $\hat{\varepsilon}_{ijt} = \ln T_{ijt} - \hat{\gamma}_t - \hat{d}_{\overleftrightarrow{ij}}$, where $\hat{\gamma}_t$ and $\hat{d}_{\overleftrightarrow{ij}}$ are time- and dyad-level controls, respectively. The x-axis variable, ln Opposite-direction trade value residuals, is defined as $\hat{\varepsilon}'_{ijt} = \ln X_{jit} - \hat{\gamma}_t - \hat{d}_{\overleftrightarrow{ij}}$. Regression results are in Table 2, column 1.

Sources: Drewry, Census Bureau, and author's calculations

STYLIZED FACT 2: *A positive deviation from the average freight rates from i to j is correlated with a positive deviation from the average containerized trade value from j to i. The same applies for containerized trade weight, while the opposite applies for value per weight.*

This relationship is made up of two components. First, intuitively, trade value and weight from *j* to *i* decrease with freight rates on the same route (see online Appendix Table A.2). Second, freight rates are negatively correlated within a route, as established in the first stylized fact. As such, freight rates from *i* to *j* *increase* with opposite-direction trade value (*j* back to *i*, Figure 2). The opposite relationship applies for value per weight due to the first component of the linkage being positive—value per weight increases with freight rates.

Specifically, within a dyad, a 1 percent deviation from the average opposite-direction trade value (from *j* to *i*) is correlated across time, with about a 0.09 percent increase in average freight rates in the going direction from *i* to *j* (column 1, Table 2 and Figure 2). In column 2, a within-dyad 1 percent increase from the average opposite-direction trade weight is correlated across time, with about a 0.1 percent increase in average freight rates in the going direction. This relationship is inverted with value per weight: a 1 percent increase from opposite-direction value per weight is correlated with an almost 0.2 percent *decrease* in average freight rates.

Table 2—Regression of Freight Rates on Opposite-Direction Trade

ln Freight rate	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln Opp-direction value	0.0909			0.116		0.0887	
	(0.0227)			(0.0188)		(0.0230)	
ln Opp-direction weight		0.122			0.127		0.121
		(0.0178)			(0.0173)		(0.0181)
ln Opp-direction value/wgt.			−0.160				
			(0.0417)				
Observations	5,684	5,684	5,684	5,294	5,294	5,684	5,684
R^2	0.523	0.557	0.518	0.564	0.586	0.520	0.555
F	15.97	47.22	14.72	37.80	54.29	14.82	45.04
Without China				Y	Y		
Without fragmented goods						Y	Y

Notes: Robust standard errors clustered by route in parentheses. Time- and dyad-level fixed effects are included for each regression. Columns 4 to 5 replicate the regressions in (1) to (2), but without China. This results in a smaller number of observations relative to the other specifications. Columns 6 to 7 replicate the regressions in (1) to (2), but without products that are typically fragmented in the production process. Value per weight results are also robust to removing China and fragmented products (see online Appendix Table A.3 due to formatting constraints).

Sources: Drewry, Census Bureau, Fort (2017), and author's calculations

These findings again provide evidence for the presence of the round trip effect. Absent this effect, there should be no systematic relationship between containerized trade in the outgoing direction and freight rates in the incoming direction. The same applies for trade in the incoming direction and freight rates in the outgoing direction.

One potential concern about these results is that the dominance of processing trade can contribute to this relationship; however, these results are robust to removing the main country that conducts processing trade with the United States—which is China (columns 4 to 5, Table 2).[24] Additionally, another potential concern could be systematic supply chain linkages between countries generally. I show that these results are also robust to this concern by removing products whose production process is typically fragmented (columns 6 to 7, Table 2). Fort (2017) constructs a dataset on plant-level decisions to fragment production in the United States at the four-digit North American Industry Classification System (NAICS) industry level.[25] Using the industries that she has identified, I remove the products in industries with a majority of production fragmentation after matching the four-digit NAICS industry to HS product codes using the concordance system from the Census Bureau. In the presence of hub-and-spoke networks as well as transshipments, my results could potentially be a lower bound (see online Appendix Section A.B for further details).

[24] The processing trade share of China exports to the United States by value is more than 50 percent in 2004 (Hammer 2006). In the example of US and China processing trade, the United States exports inputs to China, which assembles them into final goods for reexport to the United States. A decrease in the transport cost from the United States to China will decrease the input cost, which can potentially translate into larger reexport value or weight back to the United States.

[25] Examples of these industries include computers, communications equipment, and engines. For more information, see Table A.5 in Fort (2017).

B. *Identification of Round Trip Effect Impact on Freight Rates*

These stylized facts have provided correlations between port-pair freight rates as well as opposite-direction trade and freight rates, which establishes empirical evidence for the presence of the round trip effect. However, in order to identify the impact of the round trip effect on freight rates, I need to show a causal relationship between opposite-direction trade from j to i and freight rates from i to j. I require an IV that captures exogenously driven shocks to trade from j to i.

My proposed IV is a transport supply shifter. Cost shocks from j to i that affect its supply of containers will impact its corresponding freight rates on the same route. These changes to freight rates from j to i will induce an opposite shift to the freight rates from i to j due to the round trip effect. For example, a positive cost shock on the opposite-direction route ji will decrease its corresponding transport supply. As transport supply on route ji declines, its corresponding freight rates will increase. Through the negative correlation in freight rates from the round trip effect, this induces a decrease in route ij freight rates. This traces the positive relationship between aggregate opposite-direction trade from j to i (X_{jit}) and freight rates from i to j (T_{ijt}), which has been established in Stylized Fact 2.

Using X_{jit} directly to identify changes in T_{ijt} is problematic, however, if cost shocks between countries i and j are not independent. Examples of this violation include treaties between these countries that affect their bilateral trading costs (like free trade agreements (FTAs) or harmonization of standards), exchange rate fluctuations, or processing trade. As such, I introduce an instrument, in the spirit of Bartik (1991), that predicts the opposite-direction trade on route ji but is independent of the unobserved cost factors on route ij.

Instrumental Variable.—To construct my instrument, I start by showing a series of transformations on country j's total exports to i at time t (X_{jit}). Total exports is the sum of all products n that j exports to i at time t (X_{jint}). Multiplying and dividing by country j's total exports of product n to all of its partners in instrument group A (X_{jAnt}) yields the following:

$$X_{jit} = \sum_N X_{jint} = \sum_N X_{jAnt} \times \frac{X_{jint}}{X_{jAnt}} \equiv \sum_N X_{jAnt} \times \omega_{jint}, \tag{10}$$

where the first term is j's exports of n to its trading partners in set A and the second term $\omega_{jint} \equiv X_{jint}/X_{jAnt}$ is j's export share of product n to i. Both these terms are summed across all products n.

My predicted trade measure for j's exports to i is the lagged weighted sum of country j's exports to all its partners except for i. The weights are the product shares of products that j exported to i in January 2003, the earliest month available in my dataset, and the sum is country j's exports to all of its partners except for country j at present time:

$$Z_{jit} \equiv \sum_N X_{j,A\backslash i,nt} \times \frac{X_{jin0}}{X_{jAn0}} \equiv \sum_N X_{j,A\backslash i,nt} \times \omega_{jin0}, \tag{11}$$

where the first term is the sum of j's exports of product n to all its partners except for i at present time t ($X_{j,A\setminus i,nt} = \sum_A X_{jAnt} - X_{jint}$). I restrict my instrument group (set A) to high-income OECD countries following Autor, Dorn, and Hanson (2013) as well as Autor et al. (2014). The second term is j's lagged product-level export shares to i, at least eight years prior in January 2003 (time 0). Instrument Z_{jit} is obtained by summing both these terms across all products.

This instrument Z_{jit} (equation (11)) differs from the expression in (10) in two respects. First, in place of the present-time product trade shares—the first term in (10), I use the earliest shares available in my dataset from at least eight years prior—January 2003. This modification is intended to mitigate the simultaneity bias from using contemporaneous import shares. Second, I remove country i from country j's total exports of product n to all of its trading partners. This is in order to avoid a mechanical correlation between the instrument and j's direct exports to i.[26]

C. *Results*

Using my instrument, I estimate the following equation in order to establish the impact of exogenously driven shocks to opposite-direction route ji trade on route ij freight rates:

$$\ln T_{ijt} = \beta \ln Z_{jit} + \rho_{it} + \sigma_{jt} + \delta_{ij}^{\leftrightarrow} + \iota_{ijt}, \tag{12}$$

where T_{ijt} is the freight rate on route ij at time t and Z_{jit} is the instrument that predicts trade on opposite route ji at time t. I control for the time-varying propensities to export and import with exporter-time fixed effects ρ_{it} and importer-time fixed effects σ_{jt}, respectively. Additionally, I control for fixed bilateral characteristics between i and j with a dyad-level fixed effect $\delta_{ij}^{\leftrightarrow}$ that takes into account time-invariant factors like distance. ι_{ijt} is the error term, and standard errors are clustered at the route level to account for heteroskedasticity and serial correlation in the errors within routes.

In order for this IV strategy to be valid, the predicted trade measure on route ji has to be generally uncorrelated with unobserved cost determinants of ij direction freight rates ($\text{corr}(Z_{jit}, \iota_{ijt}) = 0$). Since the construction of the instrument excludes all present-time trade on the ji direction, the instrument abstracts from any bilaterally correlated present-time shocks between i and j, like bilateral treaties or the exchange rate fluctuations that were mentioned above.

Controlling for constant bilateral differences across routes as well as time-varying importer and exporter characteristics, a 10 percent increase in the opposite-direction trade measure corresponds to a significant and positive 0.4 percent increase in freight rates (Figure 3 and Table 3). This result is robust to supply chain concerns and base year changes. In order to address the concern of systematic supply chain linkages, I remove products that are typically fragmented in the production process

[26] My instrument centers around the United States due to the availability of US containerized trade data. For clarity of exposition above, I have assumed that the United States is country j and used country j's exports in my explanation above. However, if the United States is country i in the example above, I will use US imports from all its partners to construct my instrument.

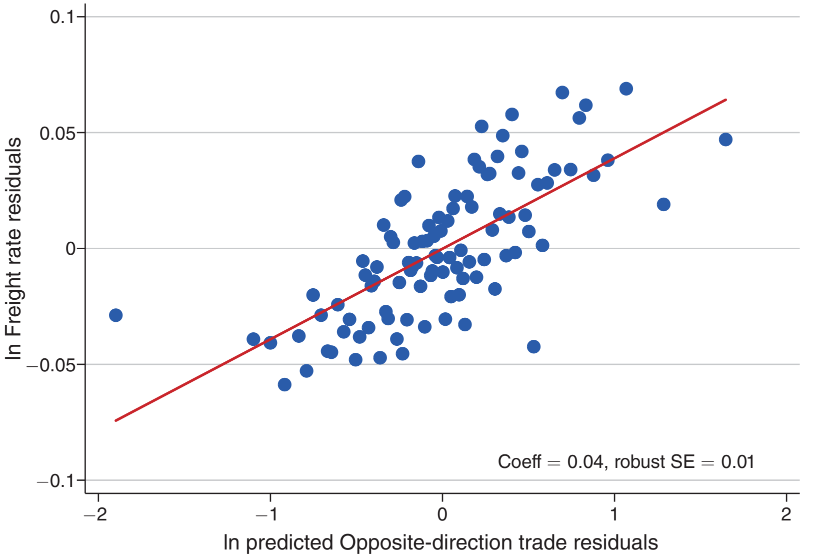

Figure 3. Residualized Plot of Correlation between Freight Rates and Instrument

Notes: Binned scatterplot with observation at the route–month level (2,307 observations). Robust standard errors clustered by route with dyad, importer-time, and exporter-time controls. The y-axis variable, ln Freight rates residuals, is defined as $\hat{\iota}_{ijt} = \ln T_{ijt} - \delta_{\overleftrightarrow{ij}} - \hat{\rho}_{it} - \hat{\sigma}_{it}$ (equation (12)). The *x*-axis variable, ln Predicted opposite-direction trade residuals, is defined as $\hat{\iota}'_{ijt} = \ln Z_{jit} - \delta_{\overleftrightarrow{ij}} - \hat{\rho}_{it} - \hat{\sigma}_{it}$. Regression results are in Table 3.

Sources: Drewry, Census Bureau, and author's calculations

Table 3—Regression of Freight Rates on Predicted Opposite-Direction Trade

	ln Freight rate (1)	ln Freight rate (2)	ln Freight rate (3)
ln Opp-direction predicted trade	0.0391	0.0245	0.0515
	(0.0138)	(0.0143)	(0.0114)
Ex–Time and Im–Time FE	Y	Y	Y
Dyad FE	Y	Y	Y
Observations	2307	2307	2326
R^2	0.964	0.963	0.965
F	7.969	2.954	20.43
Without fragmented goods		Y	
2009 base year			Y

Notes: Robust standard errors in parentheses are clustered by route. The predicted trade instrument is constructed at the HS4 level with January 2003 data using only OECD countries. Column 1 has route, exporter–time, and importer–time controls. The instrument in column 2 is constructed without products typically fragmented in the production process. Regression is run on OECD countries. The instrument in column 3 is constructed using January 2009 weights.

Sources: Drewry, Census Bureau, and author's calculations

from the instrument construction using the industries identified by Fort (2017) (column 2, Table 3). The estimates retain the same sign and are within 1 confidence interval of the baseline results. The removed products constitute about 13 percent of total trade value ($229 billion), which contributes to lower significance levels of the results. This result is also robust to an alternative base year. I reconstructed the instrument with January 2009 weights and find that my results have the same sign and are within 1 standard error of the baseline results (column 3, Table 3). This 2009 instrument has a higher significance level since it is constructed with a more recent base year relative to the start of my sample and is therefore more correlated with my sample period.

These results establish the conclusive link between opposite-direction predicted trade and freight rates, providing, in some sense, the best "test" of the round trip effect on prices.

IV. Trade Elasticity Estimation

This section presents my strategy for estimating a containerized trade elasticity with respect to transport prices. I introduce my estimating equation, explain the endogeneity issue from an ordinary least squares (OLS) estimation, and detail how the IV introduced in the previous section can address the potential biases. I then present the main results and robustness checks, followed by a discussion on how my trade elasticity estimates compare to the literature.

A. *Identification of the Impact of Freight Rates on Trade*

My estimating equation is loosely based on the canonical gravity equation (Head and Mayer 2014):[27]

$$\ln X_{ijnt} = \alpha \ln T_{ijt} + S_{it} + M_{jt} + d_{ijn}^{\leftrightarrow} + \varepsilon_{ijnt}, \tag{13}$$

where X_{ijnt} is the containerized trade on route ij of product n at time t and T_{ijt} is the container freight rate on route ij at time t.[28] I control for the time-varying export propensity of exporter country i such as production costs with an exporter-by-time fixed effect (S_{it}) and for the time-varying importer country j's determinants of import propensity with an importer-by-time fixed effect (M_{jt}). Both fixed effects also absorb aggregate time-varying shocks to these countries.

The dyad-by-product-level fixed effect, $d_{ijn}^{\leftrightarrow}$, accounts for time-invariant product-level comparative advantage differences across country pairs in addition to time-invariant bilateral characteristics like distance, shared borders, and languages.[29] $d_{ijn}^{\leftrightarrow}$ can also control for the constant tariff rate differences across countries that can contribute to differences in trade levels since the variation in tariff rates during this sample period is small—an average annual percentage point change of 0.2, with almost 80 percent of the changes being below 0.25 percentage points (see online Appendix Figure A.5). The error term is ε_{ijnt}. Standard errors are clustered at the

[27] The lack of price data hinders using a model-implied equation (equation (6)). Instead, I estimate the elasticity of trade with respect to freight rates: $\frac{\partial X_{ij}}{\partial T_{ij}} \frac{T_{ij}}{X_{ij}}$.

[28] Container freight rates are not product specific, because pricing in shipping services are generally by a combination of volume and weight.

[29] Similar specifications at the country level have been done by Baier and Bergstrand (2007) to estimate the effects of FTAs on trade flows and by Shapiro (2016) to estimate the trade elasticity with respect to ad valorem trade cost.

route level to account for general forms of heterokedasticity and serial correlation in the errors within a route. In my results, I include an additional specification with separate controls for dyad $(d_{ij}^{\leftrightarrow})$ and product (γ_n) fixed effects.

My specification exploits the panel nature of my dataset and observed per unit freight rates in order to identify the containerized trade elasticity with respect to freight rates. To my knowledge, this is the first paper to use high-frequency transportation-mode-specific panel data and its corresponding observed transport costs to identify a mode-specific trade elasticity with respect to transport costs. The paper closest to my methodology is Shapiro (2016), who uses ad valorem shipping costs across multiple modes. The key difference between my estimating equation and typical gravity models is that gravity models are estimated using ad valorem trade costs, while my container freight rate data are at the per unit level. As such, I am estimating the elasticity of containerized trade with respect to per unit freight rates and not a general trade elasticity with respect to trade cost.

The elasticity of containerized trade with respect to freight rates, α, is the parameter of interest here. As mentioned earlier, the main challenge for this exercise is that container freight rates and trade are jointly determined. As such, an OLS estimation of α in (13) will suffer from simultaneity bias. Furthermore, this bias will be downward due to two factors. The first is due to the simple endogeneity of transport costs. An unobserved positive trade shock in ε_{ijnt} will simultaneously increase freight rates T_{ijt} and containerized trade X_{ijnt}. This results in a positive correlation between T_{ijt} and X_{ijnt}, which masks the negative impact of freight rates on trade. The second factor is due to the round trip effect. Between a dyad, routes with higher demand—and, thus, higher container volume and trade value—will face relatively higher freight rates compared to routes with lower demand. This further contributes to the positive correlation between T_{ijt} and X_{ijnt}.[30] In order to consistently estimate α, I require a transport supply shifter that is independent of transport demand.

My proposed transport supply shifter to identify product-level containerized trade demand for route *ij* is its opposite-direction aggregate containerized trade shocks (on route *ji*). Aggregate trade shocks on opposite-direction route *ji* will affect the aggregate supply of containers on route *ji and* the original direction route (*ij*) due to the round trip effect. The latter provides an aggregate transport supply shifter to identify the product-level containerized trade demand for route *ij* (see online Appendix Figure A.1). A positive trade shock on the opposite-direction route *ji* in the top graph of online Appendix Figure A.1 increases its corresponding transport demand. As transport supply on that route (*ji*) responds, the aggregate transport supply in the original direction (route *ij*) will also increase due to the round trip effect. This latter aggregate increase in transport supply can identify the containerized trade demand for route *ij* conditional on demand shifts between the routes being uncorrelated. The basic idea here, then, is to utilize the round trip insight and instrument for T_{ijt} in equation (13) with its opposite-direction trade X_{jit}.

[30] It is important to highlight that the demand for containers, being a demand that is derived from the underlying demand for trade that is transported in containers, moves closely with the demand for trade that is transported in containers. I confirm this positive and significant correlation with data on container volumes from the United States Maritime Administration (see online Appendix Figure A.3).

This approach is problematic, however, if demand shocks between countries i and j are not independent. Examples of this violation include exchange rate fluctuations, processing trade, and the signing of any FTAs between countries. As such, I utilize the Bartik-type instrument introduced in the previous section (equation (11)) that predicts the opposite-direction trade on route ji but is independent of the unobserved demand determinants on route ij. The first stage of the two-stage least squares (2SLS) regression has been established in the previous section (equation (12)).

B. *Validity of Identification Approach*

My IV strategy uses the predicted trade on a route (Z_{jit}) to identify its opposite-direction product-level trade demand (X_{ijnt}). Trade on route ji (X_{jit}) is correlated with its return-direction freight rates (T_{jit}) due to the round trip effect, as established earlier. Since Z_{jit} predicts X_{jit}, the predicted trade measure Z_{jit} should be correlated with the return-direction freight rates T_{ijt} as well.

In order for my IV strategy to be valid, the predicted trade on a route (Z_{jit}) has to be generally uncorrelated with unobserved changes in product-level demand on the return-direction route $(\text{corr}(Z_{jit}, \varepsilon_{ijnt}) = 0)$. Since the construction of Z_{jit} excludes present-time j exports to country i, it is not a function of bilaterally correlated present-time demand shocks between i and j. Since Z_{jit} excludes X_{jint} for all products, any shocks that affect j's demand for i (ε_{ijnt}) that will also affect i's demand for j are no longer part of Z_{jit}. These shocks include the examples raised earlier: exchange rate fluctuations, processing trade, and the signing of any FTAs between countries.

I address potential violations with fixed effects that control for national monthly variation in container demand by importer, exporter, and fixed differences across dyad and products. These national- and dyad-level controls are at the foreign-country-and-US-port level, so these fixed effects will also absorb any US-port-level variation that is correlated with trade determinants. Therefore, my identification assumption here is that the deviation in the predicted trade measure for route ij from importer and exporter trends at the foreign-country-and-US-port level, as well as the fixed comparative advantage between i and j, is uncorrelated with the deviation in unobserved product-level demand changes.

One potential threat to my identification is correlated product-level demand shocks across countries, like in the case of supply chains. Take the example of China, which exports steel to the United States and the United Kingdom. The United Kingdom, in turn, processes the steel into a finished product, like steel cloth or saw blades to export to the United States. My instrument to identify US demand for steel products from the United Kingdom (route $UK - US$) is the opposite-direction predicted trade to the United Kingdom $US - UK$ (Z_{US-UK}), which is the sum of US weighted exports to all its trading partners except the United Kingdom (equation (11)). This means that Z_{US-UK} includes US exports to China. Now say that China experiences a supply shock, like an increase in steel manufacturing wages, that raises the input price of their steel production. There will be two effects from steel becoming more expensive. The first is that US demand for Chinese steel will fall. The second effect is that US demand for UK steel products that use

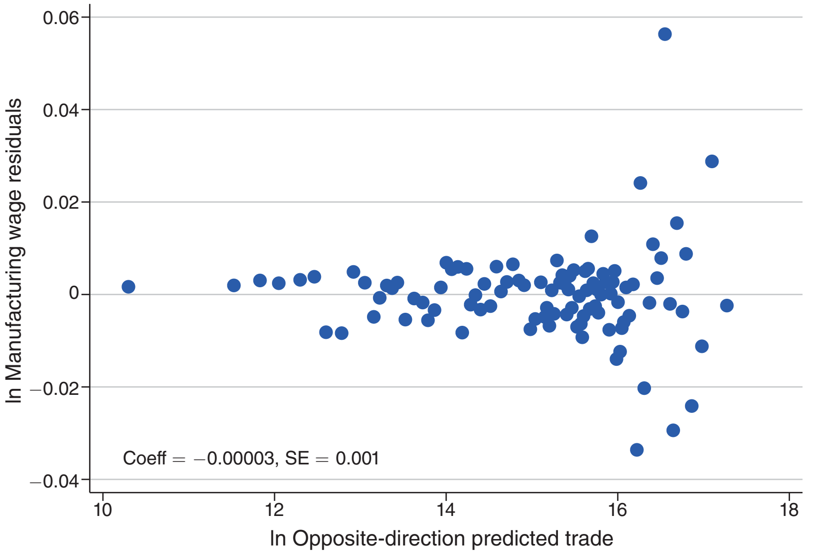

Figure 4. Residualized Plot of Correlation between Instrument and an Approximation of Demand Determinants Using Manufacturing Wages

Note: Binned scatterplot at the country–year level with 1,262 observations.

Sources: Drewry, Census Bureau, OECD, and author's calculations

Chinese steel as inputs will also fall. Through the round trip effect, US exports to China on route $US - C$ will also fall, which is included in my instrument Z_{US-UK}. This means that my instrument is correlated with the original steel supply shock in China, which affects the unobserved US demand for steel products from the United Kingdom.

In order to make sure that supply chains are not driving my results, as a robustness check, I remove products whose production process is typically fragmented in the following section. I find that my estimates retain the same sign and are within a confidence interval of my baseline results. This robustness check also helps address concerns about hub-and-spoke networks as well as transshipments.

While it is not possible to test the validity of my exclusion restriction, I can show the absence of correlation between my predicted trade measure and an approximation of ε_{ijnt}: manufacturing wages. Since most manufactured products are transported via containers (Korinek 2009) and wages are inputs to production, manufacturing wages are correlated with unobserved product-level demand determinants. Figure 4 shows this absence of correlation with a visualized regression of my predicted trade measure and manufacturing wages. Specifically, country j's predicted exports to i on route ji is uncorrelated with country i's manufacturing wages, which can approximate i's unobserved product-level demand determinants for j. While this exercise is insufficient to definitely show that my instrument is valid, it plays the same role as a balancing test in showing the absence of evidence for the exclusion restriction violation.

TABLE 4—CONTAINERIZED TRADE ELASTICITY WITH RESPECT TO FREIGHT RATES

	OLS (1)	OLS (2)	IV (3)	IV (4)
Panel A. ln Trade value				
ln Freight rate	−0.676	−0.520	−3.651	−2.795
	(0.148)	(0.133)	(0.949)	(0.903)
Panel B. ln Trade weight				
ln Freight rate	−1.061	−0.837	−4.790	−3.631
	(0.196)	(0.177)	(1.126)	(0.969)
Panel C. ln Trade value per weight				
ln Freight rate	0.384	0.317	1.138	0.836
	(0.0695)	(0.0681)	(0.224)	(0.226)
Ex–Time and Im–Time FE	Y	Y	Y	Y
Dyad FE	Y		Y	
Product FE	Y		Y	
Dyad–Product FE		Y		Y
Observations	116,887	116,887	116,887	116,887
First-stage F			12.38	10.70

Notes: Robust standard errors in parentheses are clustered by route. Results are robust to clustering at the route-and-product, dyad (two-way route), and dyad-with-products levels. All variables are in logs. Trade value, weight, and value per weight are aggregated to the HS2 level. The predicted trade instrument is constructed at the HS4 level with January 2003 data using only OECD countries. Second stage is run on OECD countries as well. Fixed effects explanation: Ex-Time FE is exporter country and time fixed effects; Im-Time FE is importer country and time fixed effects. Online Appendix Table A.4 presents the first-stage regressions.

Sources: Drewry, Census Bureau, and author's calculations

C. *Main Results*

Panel A in Table 4 presents the containerized trade value estimates.[31] Column 1 presents the OLS estimates with separate controls for importer-by-time, exporter-by-time, dyad, and products. A 1 percent increase in container freight rates is correlated with a significant 0.7 percent decrease in trade value. This estimate is robust to controlling for comparative advantage with dyad-by-product fixed effects—a 1 percent increase in container freight rates corresponds to a significant 0.5 percent decrease in trade value (panel A, column 2). After addressing the potential simultaneity bias with my predicted-return-direction trade instrument, the IV estimates are, as expected, more pronounced in magnitude. Panel A, column 3 shows that a 1 percent increase in per unit container freight rates decreases containerized trade value by 3.7 percent with separate product and dyad controls. This result is robust to including dyad-by-product controls (panel A, column 4)—a 1 percent increase in freight rates decreases trade value by 2.8 percent. The IV approach here yields trade elasticity estimates that are roughly five times more sensitive than the OLS estimates. This magnitude difference is in line with Baier and Bergstrand

[31] The first-stage results from the 2SLS regression in online Appendix Table A.4 are slightly different from the results in the previous section (Table 3 and Figure 3). This is due to differences in levels of observation. The former is at the product–route–time level, while the latter is at the route–time level.

(2007), who find a similar fivefold increase in the effect of FTAs on trade flows after taking into account of the endogeneity of FTAs.

Panel B in Table 4 presents the results using containerized trade weight as the outcome. The weight estimates are larger overall than the value estimates. This is a reflection of trade weight being a closer proxy to quantity, while value contains both quantity and price. Prices tend to increase with freight rates, while the opposite is true for quantity. The OLS estimates in panel B, column 1 show that a 1 percent increase in freight rates corresponds to a 1 percent decrease in trade weight. With the inclusion of dyad-by-product controls, the estimate decreases slightly—a 1 percent increase in freight rates decreases trade weight by 0.8 percent (panel B, column 2). In my IV estimates, a 1 percent increase in container freight rates decreases containerized weight by 4.8 percent (panel B, column 3). With dyad-by-product controls, this estimate decreases slightly—a 1 percent increase in container freight rates decreases trade weight by 3.6 percent (panel B, column 4). While the IV estimates here are not directly comparable to the literature, my OLS containerized trade weight estimates are within the range of previously established volume elasticities for other transport modes: air, truck, and rail (De Palma et al. 2011; Oum, Waters and Yong 1992).[32]

Panel C in Table 4 presents the results for containerized value per weight elasticity with respect to freight rates. This unit value calculation provides a crude measure of product quality since it is not possible to distinguish whether higher unit value means a higher-quality product within the same classification category or across product categories. The OLS estimate in panel C, column 1 shows that a 1 percent increase in container freight rates increases the average value per weight in containers by about 0.4 percent. When controlling for dyad-by-products, a 1 percent increase in freight rates increases trade value per weight by 0.3 percent (panel C, column 2). In my IV estimates, a 1 percent increase in freight rates increases containerized value per weight by 1.1 percent (panel C, column 3). This estimate decreases slightly with dyad-by-product controls—a 1 percent increase in freight rates increases containerized value per weight by 0.8 percent (panel C, column 4). My value-per-weight IV estimates are within the range of the estimates from Hummels and Skiba (2004), which finds a price elasticity with respect to freight cost between 0.8 to 1.41.

Robustness Checks.—These results are robust to a number of alternative specifications. These include removal of products typically constructed in supply chains, aggregation of time period, different product classifications, trade route imbalances, aggregation up to the route level, expansion of sample size, and change of base year. These results are also robust to alternative levels of clustering—at the route-and-product, dyad (two-way route), and dyad-with-products levels.

As mentioned earlier, the systematic presence of supply chains can potentially threaten my identification strategy. Removing the industries identified by Fort (2017) as products typically fragmented in the production process, I find that my estimates retain the same sign and are within the confidence interval of my baseline

[32] The OLS volume elasticities in these studies are between −0.8 and −1.6 (air), −0.7 and −1.1 (truck), and −0.4 and −1.2 (rail).

Table 5—Containerized Trade Elasticity with Respect to Freight Rates: Without Products Typically Fragmented in the Production Process

	OLS (1)	OLS (2)	IV (3)	IV (4)
Panel A. ln Trade value				
ln Freight rate	−0.533	−0.467	−5.979	−4.346
	(0.0980)	(0.111)	(2.695)	(2.023)
Panel B. ln Trade weight				
ln Freight rate	−0.724	−0.643	−7.769	−5.978
	(0.118)	(0.133)	(3.452)	(2.689)
Panel C. ln Trade value per weight				
ln Freight rate	0.191	0.176	1.790	1.631
	(0.0358)	(0.0375)	(0.808)	(0.766)
Ex–Time and Im–Time FE	Y	Y	Y	Y
Dyad FE	Y		Y	
Product FE	Y		Y	
Dyad–Product FE		Y		Y
Observations	258,532	258,532	258,532	258,532

Notes: Robust standard errors in parentheses are clustered by route. Products that are typically fragmented in the production process (as identified in Fort 2017) are removed from sample and the instrument. All variables are in logs. Trade value, weight, and value per weight are aggregated to the HS2 level. The predicted trade instrument is constructed at the HS4 level with January 2003 data using only OECD countries. Fixed effects explanation: Ex–Time FE is exporter country and time fixed effects; Im–Time FE is importer-country-and-time fixed effects. Online Appendix Table A.5 presents the first-stage regressions.

Sources: Drewry, Census Bureau, and author's calculations

Table 6—Containerized Trade Elasticity with Respect to Freight Rates by Time Period

	(1)	(2)	(3)	(4)
Freight rate	−2.795	−1.920	−1.645	−1.550
	(0.903)	(0.819)	(0.938)	(0.855)
Regression	IV	IV	IV	IV
Time period	Monthly	Quarterly	Biannually	Annually
Ex–Time and Im–Time FE	Y	Y	Y	Y
Dyad–Product FE	Y	Y	Y	Y
Observations	116,887	54,174	29,729	17,566
KP-F stat	10.70	22.57	23.63	55.69

Notes: Robust standard errors in parentheses are clustered by route. All variables are in logs. Trade value is aggregated to the HS2 level. The predicted trade instrument is constructed at the HS4 level with January 2003 data using only OECD countries. Second stage is run on OECD countries as well. Ex-Time FE is exporter-country-and-time fixed effects; Im-Time FE is importer-country-and-time fixed effects. The time fixed effects are aggregated in each column according to the information in "Time period." Column 1 is the baseline results from column 4 of Table 4.

Sources: Drewry, Census Bureau, and author's calculations

results (Table 5). As previously mentioned, the removed products make up about 13 percent of the total containerized value trade, which contributes to the lower significance levels of my results and the loss of instrument power.

Since my data are at the monthly period and based on trade cost variation, the magnitude of these elasticities should be higher than a more aggregated time period

Table 7—Containerized Trade Elasticity with Respect to Freight Rates: Robustness

	Baseline (1)	Homogeneous (2)	Differentiated (3)	Balanced (4)
Panel A. ln Trade value				
Freight rate	−2.795	−4.011	−2.689	−2.787
	(0.903)	(1.419)	(1.001)	(1.172)
Panel B. ln Trade weight				
Freight rate	−3.631	−4.957	−3.406	−3.916
	(0.969)	(1.535)	(1.067)	(1.406)
Panel C. ln Trade value per weight				
Freight rate	0.836	0.947	0.716	1.129
	(0.226)	(0.445)	(0.250)	(0.327)
Ex–Time and Im–Time FE	Y	Y	Y	Y
Dyad–Product FE	Y	Y	Y	Y
Observations	116,887	45,889	63,816	63,148

Notes: Robust standard errors in parentheses are clustered by route. All variables are in logs. Trade value, weight, and value per weight are aggregated to the HS2 level. The predicted trade instrument is constructed at the HS4 level with January 2003 data using only OECD countries. Second stage is run on OECD countries as well. Ex–Time FE is exporter-country-and-time fixed effects; Im–Time FE is importer-country-and-time fixed effects. Column 1 is the baseline results from column 4 of Table 4, column 2 is restricted to homogenous and reference price goods from Rauch (1999), column 3 is restricted to differentiated goods from Rauch (1999), and column 4 excludes the top and bottom quartile of trade imbalance distribution from year 2003.

Sources: Drewry, Census Bureau, and author's calculations

since they take into account the willingness of importers and exporters to substitute shipping their goods across time. Their ability to substitute is easier over a shorter time period compared to a longer period. I find that this is indeed the case: aggregating my monthly estimation to quarterly, biannually, and annually decreases its magnitude (Table 6). Between the monthly and annual time periods, my elasticity decreased by almost half (45 percent) (calculated from columns 1 and 4, Table 6). This decrease in elasticity as time period aggregation increases is also found in other studies (Shapiro 2016; Steinwender 2018).

I further evaluate these estimates by comparing the different types of containerized goods. The Rauch (1999) test predicts that the demand for homogeneous goods should be relatively more elastic compared to differentiated goods. Using the concorded product classifications from Rauch (1999), I divide my sample into homogeneous goods (grouping both homogeneous and reference price goods from his classification) and differentiated goods. I find that my results are indeed consistent with this test—my elasticity for homogenous goods is relatively higher than the baseline, while the elasticity for differentiated goods is relatively lower (columns 2 and 3, Table 7). Shapiro (2016) finds the same magnitude differences in his elasticities after dividing his sample into these product classifications.

Additionally, I show that these results are not driven by countries with which the United States has a large trade imbalance (like China). Routes with larger trade imbalances are more likely to be impacted by the round trip effect since they face a more severe backhaul problem. I find that my results are robust to restricting the sample to countries that the United States has relatively more balanced trade with in the year 2003, at least eight years prior to the analysis. My results are within 1 standard error to the baseline (column 4, Table 7).

Last but not least, these results are robust to expansion of sample size (see online Appendix Table A.6), aggregation up to the route level (see online Appendix Table A.8), and an alternative base month (using January 2009 data; see online Appendix Table A.9).[33] All these estimates have the same signs and are within 1 confidence interval of my baseline estimates.

D. *Trade Elasticity and Discussion*

As predicted by the theory model (equation (5)), the elasticity of trade with respect to transport cost is the following:

$$\frac{\partial X_{ijt}}{\partial T_{ijt}} \frac{T_{ijt}}{X_{ijt}} = (1-\epsilon) \frac{T_{ij}}{w_i \tau_{ij} + T_{ij}} \equiv \alpha. \tag{14}$$

This elasticity is equivalent to the above estimated elasticity of trade with respect to freight rates, α (equation (13)). In order to obtain trade elasticity with respect to price (ϵ), I approximate the freight rate share of price ($T_{ij}/(w_i\tau_{ij} + T_{ij})$) with the estimate by Irarrazabal, Moxnes, and Opromolla (2015). They calculate that per unit trade cost is about 14 percent of the median price.[34] The trade elasticity ϵ calculated from equation (14) is 20.96.

The trade elasticity estimated in this paper is short-run elasticity at the monthly and port level for containerized trade, which takes into account endogeneity concerns between trade and trade cost. This elasticity differs from the estimates in the general trade literature (which are typically smaller in magnitude) in three main ways that are described below. Following this, I show that both my weight and value per weight estimates using the same empirical specification (Table 4) are well within the range of what previous studies have found. Lastly, I introduce a simple model that illustrates the two sources of bias in this paper—simultaneous equation bias and bias induced by the round trip effect—and show that they contribute to a larger difference between the OLS and IV estimates. I then solve for the implied supply elasticity using my IV and OLS estimates and show that it is in the ballpark of available supply elasticities in the literature.

Trade Costs Are Generally Modeled as Exogenous: While there are recent exceptions, trade elasticity estimates typically do not take into account the reverse causality of trade costs with respect to trade flows. In fact, the OLS estimates in this paper imply a trade elasticity of 4.7 that is very much in line with the literature (column 2, panel A, Table 4). When taking into account the endogeneity between transport cost

[33] The January 2009 results intuitively has more power in the form of a higher first-stage F-stat compared to the baseline since it closer to and more correlated with the start of my data period.

[34] It is acknowledged here that per unit trade cost includes not just transport costs but also quotas and per unit tariffs. However, the significance of transport costs has been increasing in recent years due to global decreases in tariffs and other formal trade barriers (Hummels 2007), and so it is assumed here that transport costs make up most of the per unit trade cost.

and trade flows, the IV estimates here imply a four- to fivefold increase from the OLS estimates. This increase in magnitude is in line with previous literature that has taken into account the endogeneity of trade costs. Specifically, Baier and Bergstrand (2007) finds a similar fivefold increase in the effect of FTAs on trade flows after taking into account the endogeneity of FTAs. Trefler (1993) finds an even larger, tenfold increase in the impact of nontariff trade barriers when trade protection is modeled endogenously compared to when it is treated as exogenous.

Typical Estimates Are Usually at the Country Level and for All Products: In order to effectively control for multilateral resistance terms in this paper to eliminate any importer- and exporter-specific sources of selection bias (Limão 2016), I conduct my analysis at the US-port-and-foreign-country level. As such, potential substitution across US ports (Los Angeles/Long Beach, New York, and Houston) could account for the elasticity in this paper being larger than what is typically found in the literature. If the freight rates out of the Houston port increases, for example, then an exporter could choose to export out of the New York port instead. Typically, these elasticities are estimated at the country level, and these margins of substitution would not apply. As a result, even when I aggregate my trade elasticity to the annual level (as seen in the next point below), its magnitude is still larger than what is typically found in the literature due to the potential for port-level substitutions. This is echoed in Asturias (2020), which finds an elasticity of substitution across port pairs of 13.9 using cross-section data from 10 US ports to 300 foreign destinations, which is much higher than typical country-level elasticities of substitution.

Additionally, the trade elasticity estimated in this paper is for containerized goods. Since the majority of manufacturing goods are containerized (Korinek 2009), this elasticity is more comparable to a product-level elasticity for manufacturing. Shapiro's (2016) 6-month manufacturing trade elasticity of 7 is within 1 standard error of my 6-month trade elasticity (calculated from column 3, Table 6). My annual trade elasticity of 12.6 (calculated from column 4, Table 6) is within the ranges of 3.6–12.86 estimated by Eaton and Kortum (2002) and 0.37–51.08 by Caliendo and Parro (2015).

Trade Elasticity Estimates Are Usually Longer Run, Focused on One Year or More: Since my product-level trade elasticity is at the monthly level, the magnitude of my elasticities should be higher than a more aggregated time period since they take into account the willingness of traders to substitute shipping their goods across time. For example, a car manufacturer would be able to substitute its demand for imported tires from August to September, but it is unlikely to be able to substitute from using tires at all for six months or a year. The ability of importers and exporters to substitute is easier over a shorter time period compared to a longer period.

My results reflect this: aggregating my monthly estimation upward decreases its magnitude (Table 6). My elasticity decreased by almost half (45 percent) between the monthly and annual time periods, which decreases my trade elasticity to 12.6 (calculated from columns 1 and 4, Table 6), although it is acknowledged that the standard errors are relatively large at higher aggregations. This decrease in elasticity as time period aggregation increases is also found in other studies. Shapiro (2016) finds that his elasticity is almost halved when aggregating from the biannual level to the annual level, while Steinwender (2018) also sees a substantial decrease in her daily demand elasticity when aggregating up to three months.[35]

Furthermore, while there isn't a direct comparison of the trade elasticities in this paper to the literature, I show that both my weight and value per weight elasticity with respect to freight rate estimates are well within the range of what previous studies have found. My OLS weight estimates of -0.8 to -1.1 (Table 4) are within the range of previously established OLS volume elasticities for other transport modes in the transport literature (De Palma et al. 2011; Oum, Waters and Yong 1992): -0.8 to -1.6 (air), -0.7 to -1.1 (truck), and -0.4 to -1.2 (rail). In addition, my value-per-weight IV estimates of 0.84 to 1.1 are squarely within the estimates from Hummels and Skiba (2004), which finds a price elasticity with respect to freight cost between 0.8 to 1.41.

Last but not least, I introduce a simple model incorporating the two sources of bias in this paper and show that implied supply elasticity is in the ballpark of existing estimates in the literature (see online Appendix A.E for further details). There are two sources of bias here: (i) simultaneous equation bias, since the supply and demand for transport services on a particular route *ij* are simultaneously determined, and (ii) bias induced by the round trip effect, where transport supply for routes *ij* and *ji* is jointly determined, leading to a negative relationship between the transport prices on route *ij* and *ji*. Both these sources of bias contribute to larger-magnitude differences between the OLS and IV estimates in my results, as predicted in Table 4. After calibrating and solving for the supply elasticity implied by this model, I show that my estimate of about 0.78 is in the ballpark of Broda, Limao, and Weinstein (2008), which estimates a median elasticity of supply of 0.6 across 15 importers annually over the period 1994–2003.

V. Counterfactual Implications for Trade Policy

In order to evaluate the implications of the round trip effect effect for trade policy, I simulate two counterfactual import tariff changes in a quantitative Armington trade model utilizing my estimated trade elasticities and theory framework. The first counterfactual doubles US import tariffs on all trading partners from its 2014 average of 1.33 percent, while the second counterfactual simulates the impact of the Trump administration's Section 301 tariffs on China. I first describe the calibration and estimation process below and then present my counterfactual results.

[35] The elasticity in Boehm et al. (2020) is estimated from tariff changes over a much longer time horizon (one to ten years), where substitution margins may be operative due to firm entry or switching of suppliers resulting in larger elasticities in the longer run. Additionally, anticipatory behavior from future tariff changes would imply an upward bias of the trade elasticity. The trade elasticity in this paper is estimated from trade cost variations from month to month—less permanent in nature—which results in higher monthly elasticities than a more aggregated time period since they take into account the willingness of traders to substitute shipping their goods across time. The two sources of bias in this paper are discussed in detail in online Appendix A.E.

A. *Taking the Model to Data*

I use tariff rates (τ_{ij}) from the trade-weighted, effectively applied tariff rates for manufacturers from the World Bank. Manufacturing import tariffs are chosen since the majority of manufactured products are transported via containers (Korinek 2009). The round trip marginal cost for each port pair is the sum of the freight rates going both ways $(c_{ij}^{\leftrightarrow}$, equation (4)). Input prices (w_i) are approximated by hourly manufacturing wages from the OECD following Eaton and Kortum (2002). The availability of OECD wages limits the countries in this analysis. Specifically, the lack of comparable manufacturing wages excludes Asian countries like Hong Kong and India. To include China, I approximate its manufacturing wages from US OECD manufacturing wages using the harmonized minimum wage ratio (0.3) between China and the United States from the International Labor Organization (ILO).[36]

The remaining preference parameter and the loading factor are chosen to match the observed trade value and freight rates in my dataset given the equilibrium conditions below for each country pair. The preference parameter a_{ij} captures j's preference for i's good. The loading factor l_{ij} captures the average container volume required per quantity of good traded along route ij. This relaxes the balanced trade quantity assumption in the theory model since both the preference and loading parameters will adjust in order to balance the equilibrium quantity of container volumes between i and j, which is the loading factor multiplied by the quantity of goods. The loading factor affects the traded goods price as well as the profits of the transport firms (equations (2) and (3), respectively, in the theory section):

$$p_{ij} = w_i \tau_{ij} + T_{ij}/l_{ij}$$

$$\pi_{i,j} = T_{ij} l_{ij} Q_{ij} + T_{ji} l_{ji} Q_{ji} - c_{ij}^{\leftrightarrow} \max\{l_{ij} Q_{ij}, l_{ji} Q_{ji}\},$$

where Q_{ij} is the quantity of goods traded on route ij. In equilibrium, the container volumes between i and j are the same: $l_{ij} Q_{ij}^* = l_{ji} Q_{ji}^*$.

The equilibrium freight rates and containerized trade value for route ij, including loading factors l_{ij} and l_{ji}, can be derived from the price and profit functions above, as well as the optimality conditions from the theory section (equations (4) and (5)):

$$T_{ij}^* = \frac{1}{1 + Y_{ij}} \left[c_{ij}^{\leftrightarrow} + l_{ji} w_j \tau_{ji} - Y_{ij} l_{ij} w_i \tau_{ij}\right]$$

$$X_{ij}^* = p_{ij} Q_{ij} = \left[\frac{\epsilon}{\epsilon - 1} \frac{1}{a_{ij}}\right]^{-\epsilon} \left[\frac{1}{1 + Y_{ij}} \left(w_i \tau_{ij} + \frac{1}{l_{ij}}\left(c_{ij}^{\leftrightarrow} + l_{ji} w_j \tau_{ji}\right)\right)\right]^{1-\epsilon},$$

where

$$Y_{ij} = \frac{a_{ji}}{a_{ij}} \left(\frac{l_{ji}}{l_{ij}}\right)^{1+1/\epsilon}.$$

[36]The UK and US ILO harmonized minimum wage ratio is the same as their OECD wage ratio (1.02), which serves as a basis for this approximation.

Table 8—Trade Predictions from Doubling US Import Tariff

Model	Freight rate	Trade value	Trade balance (exports/imports)
Round trip			
Import	−0.12%	−1.14%	−0.57%
Export	+0.19%	−1.71%	
Exogenous			
Import	0	−2.35%	+2.41%
Export	0	0	

Notes: Freight rate changes are average percent changes across 26 routes, while trade value and imbalance changes are total percent changes. Import tariffs are the 2014 trade-weighted effectively applied tariff rates for manufactures. Average US import tariff is 1.33 percent with the minimum being 0.09 percent (Australia) and the maximum being 2.69 percent (China). Domestic input prices are approximated by hourly OECD manufacturing wages and ILO harmonized wages.

Source: Author's calculations using Census Bureau, Drewry, ILO, OECD, and World Integrated Trade Solution (WITS)

I am able to match the observed freight rates and trade value data exactly because my model is just identified. Since the results below are based on 2014 data, I construct an out-of-sample model fit instead for 2015 trade value and freight rates using my estimated parameters. Between my estimated values and the observed 2015 data, I fit the out-of-sample data well, with high correlations of 0.71 for trade value and 0.74 for freight rates (see online Appendix Figure A.6).

B. *Counterfactual: Doubling US Import Tariffs*

Table 8 shows the trade predictions from doubling US import tariffs on its trading partners. The initial trade-weighted average is 1.33 percent. The first two rows, labeled as "Round Trip," show the predicted percent changes in import and export freight rates, trade value, and overall trade balance for the round trip effect model. The next two rows, labeled as "Exogenous," show the predicted changes for a model with exogenous transport costs.

The results in Table 8 echo the predictions from Proposition 1. The round trip model predicts that US import freight rates will fall by 0.12 percent to mitigate the US tariff increase. Even though import freight rates are now smaller, US import value decreases overall by 1.14 percent (as predicted by Lemma 1). The model with exogenous transport costs predicts a larger decrease in import value (2.35 percent) since it does not take into account the mitigating effect from transport costs. Furthermore, the round trip effect will generate spillovers from this tariff increase onto US exports. US export freight rates are predicted to increase by 0.19 percent, while US export value decreases by 1.71 percent.[37] The exogenous transport cost model predicts no changes on the export side.

[37] The estimates in Hayakawa, Ishikawa, and Tarui (2020) from doubling their tariff rates are approximately six to seven times larger than these results. One reason for this discrepancy, other than differences in empirical methodology, is the differences in our samples. The United States has a low average tariff rate of 1.33 percent, while their sample, which includes many developing countries, has a much higher average tariff rate of 6 percent.

From comparing both models, three main observations can be made. First, the exogenous transport cost model predicts no changes in freight rates when US manufacturing import tariffs are doubled. The round trip model, however, predicts a fall in the import freight rates to mitigate the effects of the tariff increase, as well as a rise in export freight rates due to spillovers from the round trip effect. Second, the exogenous transport cost model predicts no changes in exports, while the round trip model shows a fall in export value as a result of higher export costs. Third, the exogenous model predicts a larger fall in import trade value relative to the round trip model—by about 35 percent. This overprediction is robust to using other trade elasticity estimates as well. With the trade elasticity of 5, as suggested by Head and Mayer (2014), the exogenous model overpredicts the average import value increase by a very similar amount, 34.6 percent. Last but not least, the exogenous model's trade balance (ratio of exports to imports) is predicted to improve, while the round trip trade balance deteriorates.

The overprediction of the fall in imports or mitigation effects between the exogenous and round trip model is large and robust to using different trade elasticity estimates. This is because the trade elasticity adjusts the imports' response to tariffs proportionally, with and without the endogenous round trip adjustment. I confirm this by showing a high correlation of 0.9 of between the route-level mitigation effects using both elasticities (see online Appendix Figure A.8). I also show analytically that this is particularly true for smaller ranges of tariff changes. Lastly, I show that the factors driving the mitigation effects are the unit-adjusted relative preferences for routes. A higher unit-adjusted relative preference for route ij means that consumers have a higher preference for ij goods compared to ji goods. This means that an increase in j's import tariffs on i will result in a smaller import flows decrease due to this high relative preference. As a result, the mitigation impact from the round trip effect for route ij will be smaller. I confirm that this is the case by showing a highly positive correlation of 0.96 between the route-level unit-adjusted relative preferences against its mitigation effects. I further elaborate on the model and data features that drive these results in online Appendix Section A.F.

These differences in trade predictions have important policy implications. If a country chooses to pursue protectionist policies by increasing their import tariffs and they estimate their trade outcomes using a model with exogenous transport costs, they will overpredict the level of protection they are affording their local industries—the fall in imports from their trading partners—and predict no other direct impact on their exports and transport costs. As a result, the exogenous model will predict an improvement in the country's overall trade balance with its partners. However, a model that endogenizes transport costs with respect to the round trip effect will paint a very different picture: while the country's imports fall, so will its exports. The combination of the exports decreases (due to the spillover effect), and the smaller mitigated imports decrease results in the opposite intended effect: a worsening of the country's trade balance.

In order to estimate a tariff equivalent of the round trip effect, I calculate the change in export prices due to increases in US import tariffs. From the proof for Lemma 1 and equation (A.4) in the online Theory Appendix, the derivative of

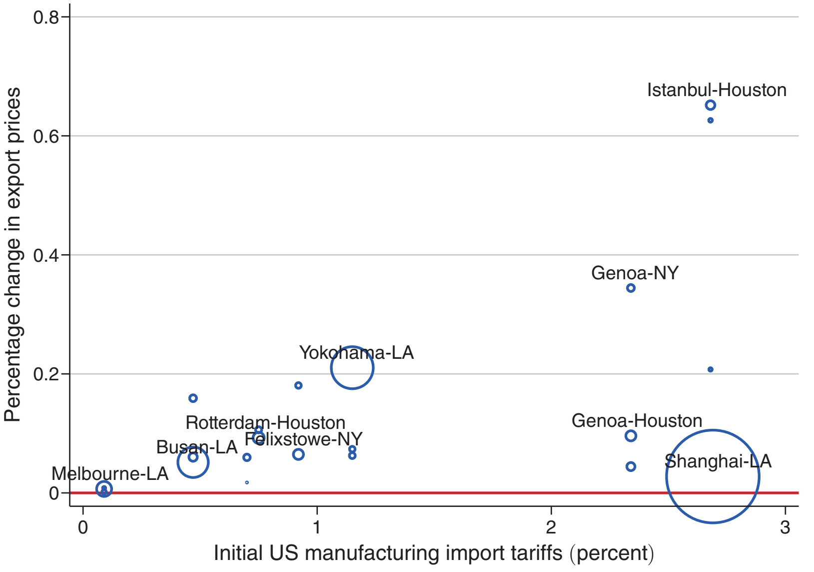

Figure 5. Port-Level Export Price Increases from Doubling US Import Tariffs

Notes: Circles denote trade share of route. Red line denotes no change in export prices, which is predicted if transport costs are exogenous. Trade-weighted, effectively applied tariff rates are used.

Sources: WITS, OECD, Drewry, Census Bureau, and author's calculations

US export prices with respect to US import tariffs is a positive constant. As such, the round trip effect from this model predicts a constant export tax of 0.1 percent on prices when US import tariffs on its partners are increased by a factor of 1.

The results from this counterfactual are calculated across 22 port-level routes between the United States and its OECD trading partners. Figure 5 shows that this increase in export prices is different across routes, ranging from a 0.01 percent increase for the Melbourne–Los Angeles route, which has a very low initial US tariff of 0.9 percent, to a 0.68 percent increase for the Istanbul–Houston route, which has a higher initial tariff of 2.7 percent. Since the counterfactual exercise here increases initial US tariffs by a factor of one, countries with higher US initial tariffs will see bigger increases in export prices. Conditional upon the port pairs being in the same countries, the differences in export prices are driven by route-specific data and parameters. For example, the Genoa–New York and Genoa–Houston routes have different changes in export prices, although the US import tariff for Italy is the same for both routes. US exports on the Genoa–New York route are about 3.5 times higher in value compared to US imports, resulting in a higher export preference parameter relative to imports. This also results in a lower loading factor on the export side relative to the import side. The Genoa–Houston route, on the other hand, has more US imports relative to exports. These differences mean that the Genoa–New York route has a bigger increase in its export prices than the Genoa–Houston route after the United States doubles its import tariffs on Italy (equation (15)).

Table 9—Trade Predictions from US Section 301 Tariffs on China

Model	Freight rate	Trade value	Trade balance (exports/imports)
Round trip			
Import	−0.08%	−3.56%	−0.11%
Export	+0.25%	−3.67%	
Exogenous			
Import	0	−5.02%	+5.28%
Export	0	0	

Notes: Freight rate changes are average percent changes across three US–China routes, while trade value and imbalance changes are total percent changes. The trade-weighted average US Section 301 import tariff on China in February 2020 is 19.3 percent (Bown 2020). Domestic input prices are approximated by hourly OECD manufacturing wages and ILO harmonized wages.

Source: Author's calculations using Census Bureau, Drewry, ILO, OECD, Bown (2020), and WITS

C. *Counterfactual: US Section 301 Tariffs on China*

In 2018, the Trump administration started a series of sharp import tariff increases on its major trading partners. China was particularly targeted. These tariffs were authorized after a trade investigation was conducted under Section 301 of the Trade Act of 1974. By February 2020, the US trade-weighted average tariff rate on China was 19.3 percent (Bown 2020).

I simulate the results from this increase in US import tariffs on China (Table 9). Here, the relative gap between the average freight rate changes is much larger (a 0.08 percent decrease in imports freight rates, compared to a 0.25 percent increase in export freight rates). This is due to the high unit-adjusted relative preferences for China–US routes, which reduces the mitigation effect on import freight rates as well as import flows. On the exports side, the opposite-direction route (US–China) has a low unit-adjusted relative preference, which translates into larger spillover effects in terms of export freight rates and export flows. As a result, the US–China trade balance will worsen by 0.1 percent.

Relative to the round trip model, the exogenous transport cost model overpredicts the imports decrease and does not predict any export changes (as well as any freight rate changes). This results in the exogenous model predicting a trade balance improvement of about 5 percent for the United States, while the round trip model finds the opposite—a worsening of the trade balance. The mitigation effect from the import fall across both models is 29 percent, which is again roughly similar using a trade elasticity of 5 (32.6 percent).

VI. Conclusion

This paper provides a microfoundation for transport costs by incorporating the round trip effect, an optimal strategy due to cost considerations employed by various transport carriers, including container ships, cargo airlines, and trucks. The first contribution of this paper is to identify the round trip effect empirically. The main implication of the round trip effect is the negative correlation in freight rates within port pairs. This paper is the first to provide systematic evidence for this negative correlation. To address the endogeneity between freight rates and trade flows, I construct a novel IV using the round trip insight to establish the impact of the round trip effect on freight rates—an exogenous negative shock to trade from i to j induces a positive increase in freight rates from j to i.

The second contribution of this paper is to estimate a trade elasticity with respect to transport price for containerized products. I find that a 1 percent increase in average freight rates will decrease average containerized trade value by 2.8 percent, decrease average containerized trade weight by 3.6 percent, and increase average containerized trade quality by 0.8 percent.

The third contribution simulates counterfactual import tariff changes in a quantitative model in order to evaluate the implications of this effect for trade policy. I show that the counterfactual tariff increase does not just decrease US imports to its trading partners, it also decreases US exports to the same partners. A trade model with exogenous transport costs would overpredict the import decrease by 30–35 percent relative to the round trip model and not predict any associated bilateral export decrease at all. This results in the exogenous model predicting a trade balance improvement from protectionist policies while the round trip model shows the opposite: a worsening of the trade balance.

It is acknowledged here that the assumption of exogenous iceberg trade costs, often to be symmetric, is not an assumption that trade economists ever argued to be realistic. Instead, this assumption is made for tractability. So under what conditions is it essential to incorporate the insights from this paper? First, the round trip effect would be important to incorporate when one is estimating trade costs for routes with high mitigation effects (see online Appendix Figure A.9). These are routes with low unit-adjusted relative preferences and ones where the predicted trade difference between the round trip and exogenous model would be the largest. Examples of these routes are Felixstowe–Los Angeles and Genoa–Houston. Generally speaking, these routes have relatively similar ratios of exports and imports, along with export and import freight rates.

Second, the round trip effect would be important to incorporate on big routes, where ships are more likely to go back and forth from hub port to hub port in fixed routes. Ganapati, Wong, and Ziv (2021) finds evidence that the global container shipping takes place on a hub-and-spoke network, with bigger countries or hubs tending to ship more directly to the United States with fewer stops along the way—meaning that they are more likely to be subjected to the round trip effect.

Third is when studying goods that are shipped over transportation modes that are subject to the round trip effect. These include goods transported in containers, trucks, and air cargo. Examples of goods that are not shipped via round trips are like grains and coal, which are shipped in bulk liner ships, or oil, which is shipped in oil tankers. These bulk liner and tanker ships are likely to depart from their destinations without cargo and therefore have to search for their next load, like taxis, while container ships have fixed publicized schedules since they are able to pick up a wide variety of cargo at each stop, like buses.

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