Trade, Transport Costs, and Trade Imbalances:

An Empirical Examination of International Markets and Backhauls*

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Abstract

The U.S. trade deficit has been growing for over 25 years and has been accompanied by enlarging freight rate differentials. While traditional models of trade have ignored these gaps assuming symmetry across all bilateral trade costs, the specific linkages between trade imbalances and international transportation costs have remained unexplored. Given the current trade policies, the implications arising from the endogenous adjustment of bilateral transport costs to policy-induced changes in the U.S. trade deficit, for example, are of particular importance. To break new ground on this issue, we develop and estimate a model of international trade and transportation that accounts for the effects of persistent trade imbalances. The theoretical results are supported by our empirical analysis and indicate that bilateral transport costs adjust to a country's trade imbalance. The implication is that a unilateral import policy, for example, will cause spillover effects into the bilaterally integrated export market. To illustrate, we use our empirical results to simulate the anticipated spillover effect from the Chinese ban on waste imports. We find that China's ban and the projected 1.5% rise in the U.S. trade deficit will not only lead to a 0.77% reduction of transport costs charged on U.S. exports to China, but also a 0.34% increase in transport costs on U.S. imports from China.

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1 Introduction

International trade has been growing for decades and has been rising faster than world gross domestic product [Blonigen and Wilson, 2013]. This growth has put tremendous pressure on international transport markets, which have responded with considerable innovations; most notably the introduction of containers in the late 1950's. The resulting reduction of international transport costs, along with rising incomes, has fueled the growth of international trade[1] and the interest in developing models that connect trade and transportation.

The growth in trade, however, has varied drastically across countries and has resulted in a significant shift in global trade patterns as well as large regional, national, and bilateral trade imbalances.[2] As import growth has exceeded that of exports over the last 25 years, the U.S., for example, currently exhibits the largest of all national trade deficits with imports exceeding exports by $736 billion. Based on U.S. Census data, Figure 1 illustrates that this aggregate difference in exports and imports is largely due to the growing bilateral trade deficit with China ($347 billion in 2016). The central questions addressed by this study contemplate the implications of these growing trade imbalances from the transportation and policy perspectives. First, we derive and estimate the elasticity of trade with respect to international container freight rates. Differentiating between the two bilateral shipping routes, we explore the linkages between these transportation costs and their dependence on growing bilateral trade imbalances. Lastly, we consider the policy implications arising from these bilateral trade, trade imbalance, and transport cost dependencies and illustrate the economic significance of our findings via a counterfactual exercise motivated by the recently implemented Chinese import waste ban.

[1] A recent study by Bernhofen et al. [2016] finds that the reduction in transport costs due to containerization has had a significant impact on the growth of international trade. In particular, the authors find that the cumulative average treatment effect (ATE) of containerization on 'North-North' trade 15 years after treatment is 1240%.

[2] We define the term 'trade imbalance' to indicate the fact that the volume or value of bilaterally traded products in one direction diverges from that in the opposite direction. The actual magnitude of this imbalance is labeled as the difference in trade, whereas the directionality of this imbalance is defined by the commonly referred to trade deficit or trade surplus between two trading countries. We adopt this terminology throughout this study.

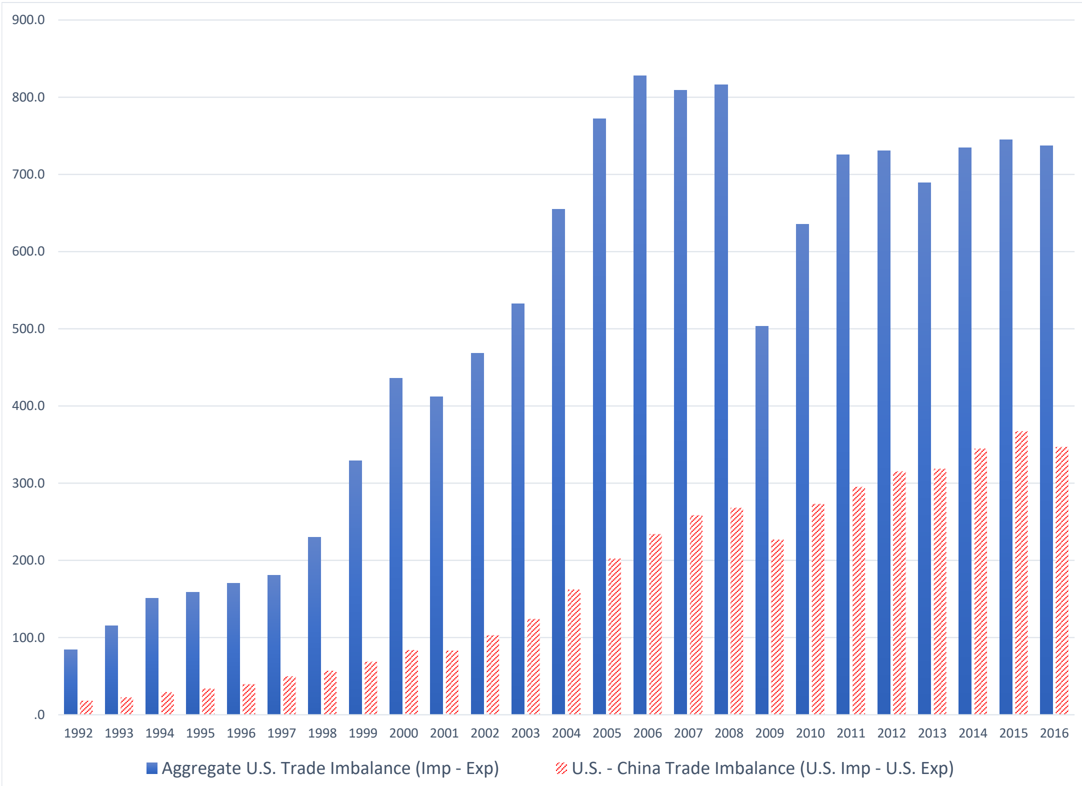


Figure 1: U.S. Trade Imbalance ($ Bil.) (Source: U.S. Census Bureau)

We evaluate these key relationships via a sample of containerized trade and freight rates recorded for the three primary global markets between the U.S., Asia and the EU. Addressing the first point of emphasis, our empirical results indicate a very inelastic, but not unexpected[3] response in trade to a persistent change in transport costs. We find that a 1% permanent increase in freight rates reduces the long-run volume of containerized trade by 0.058%.[4]

[3]Egger [2002], for example, compares gravity results and the distance effect for several different panel estimators. The author finds large variation in coefficient estimates across estimators and argues that part of this variation stems from short-run versus long-run considerations. In particular, the author's estimates show that the effect of unit-specific trade costs, controlled for via distance, drastically declines in magnitude from -0.915 in the short-run to -0.178 when considering the long-run. In comparison, our estimate yields a trade elasticity with respect to international transport costs that measures about one third of the long-run distance effect suggesting that distance is a crude proxy that captures more than just international freight rates.

[4]Although this estimate may appear small, it is not an unreasonable long-run elasticity given the fact

Based on this estimate and our data sample, a 1% persistent increase of transport costs corresponds to a \$12.5 rise in the average real freight rate and causes a long-run average decline in the volume of containerized trade by about 2,680 twenty-foot containers per year ($\approx$ 0.058% of annual container flows). Based on the immense variation in container cargo retail values (\$10,000 to \$1.8 million) reported by Rodrigue et al. [2013], this inelastic long-run reduction in the volume of containerized trade corresponds with a persistent decline in the value of containerized trade ranging from \$26.8 million to \$4.8 billion per year.

Secondly and perhaps more importantly, our theoretical and empirical analyses break new ground by integrating bilateral transport costs. The estimates not only support our theoretical predictions, but provide novel empirical evidence that bilateral transport costs inversely depend on the respective trade imbalance. While transport costs on U.S. imports, for example, increase by 0.23% in response to a permanent 1% rise in the U.S. trade deficit, freight rates charged on U.S. exports simultaneously decrease by 0.52%. Our estimate of the asymmetric simultaneous adjustment of bilateral transport costs quantifies one of the critical mechanisms by which bilateral spillover effects can be induced and marks one of the key contribution of our study.

To illustrate the economic significance and magnitude of the indicated spillovers across bilateral trade markets, we use our findings to simulate the bilateral impacts of a variety of hypothetical unilateral trade and transport shocks. Naturally, these simulated shocks are potentially policy driven and therefore, applicable to number of current initiatives. One very relevant example of this is the recent shift in Chinese trade policy banning all waste imports. As of July 2017, China announced that it will ban imports of 24 categories of solid waste by the end of the year. According to U.S. Census data, these types of waste constitute the sixth largest U.S. export to China, totaling roughly \$5.1 billion in 2016. While U.S. exporters of these products are scrambling to find alternative markets, the U.S. trade deficit

that container freight rates represent only a small fraction of the value of the goods being shipped. The average freight-rate-to-container-value ratios, in fact, range from less than 1% for the shoe and apparel industries to almost 20% for containerized appliances and furniture [Rodrigue et al., 2013].

is set to worsen by the end of the year. Counterfactual calculations based on our estimates and simulations suggest that China's ban on imported waste and the projected 1.5% rise in the U.S. trade deficit will lead not only to the expected 0.77% permanent reduction of freight rates charged on U.S. exports to China, now facing lower transport demand, but also a 0.34% long-run increase in freight rates charged on the integrated bilateral shipping routes facilitating U.S. imports from China.[5] Given the resulting long-term adjustments in trade, the anticipated freight rate changes will cause a bilateral spillover effect that leads to a traditionally unanticipated reduction in Chinese exports in addition to the expected decline of its imports. Together, these findings not only indicate the previously studied endogeneity of unilateral trade costs, but also the largely unexplored spillover effects arising from the integration of bilateral transport costs and their dependence on the bilateral trade imbalance.

While there is a plethora of models of international trade[6] and multitude of empirical studies[7] that have pointed to the importance of trade and transport costs [Hummels, 2001, Anderson and van Wincoop, 2004, Behrens et al., 2006, Hummels, 2007, Hummels et al., 2009, Kleinert and Spies, 2011], few studies have considered the connections between trade imbalances and bilateral freight rates, as well as the consequences thereof. Exceptions include research by Behrens and Picard [2011], Takahashi [2011] as well as Jonkeren et al. [2011], which are most closely related to our study. Both Behrens and Picard [2011] and Takahashi [2011] offer a strictly theoretical treatment of this subject and show that bilateral transport costs counteract the associated trade imbalances and agglomeration of economic activity.

[5]These freight rate projections are based on a 1.5% increase in the trade deficit in terms of value. If we assume that waste, such as scrap metal and plastics, have an above average weight-to-value ratio the impact on the trade deficit in terms of volume will be even larger. Since our primary analysis relies on volume data, this suggests that our calculations may provide a conservative estimate of the potential long-run freight rate changes.

[6]See, for example, Samuelson [1952], Dornbusch et al. [1977], Krugman [1979], Eaton and Kortum [2002], Bernard et al. [2003] or Melitz [2003], among others.

[7]See, for example, studies by Bergstrand [1985], Thursby and Thursby [1987], McCallum [1995], Anderson and van Wincoop [2003] and Carrere [2006] or surveys by Jacks et al. [2008], Bergstrand and Egger [2011] or Anderson [2011].

In contrast, Jonkeren et al. [2011] move beyond their theoretical framework[8] and present empirical evidence of the dependence of transport costs on trade imbalances in a multi-regional setting. Focused on barge shipments on European inland waterways, the authors show that regional rather than route-specific trade imbalances drive European barge freight rates. In their analysis, however, the authors specifically exclude containerized cargo, one of the predominant modes of international trade, and limit the geographical scope of their analysis.

In the present study, we expand upon this recent literature by developing and estimating a model of trade and transportation. We derive the demand for transportation based on trade determinants and incorporate the supply-side of transportation in the spirit of Behrens and Picard [2011]. An important feature of our framework is the fact that transportation supply is provided between pairs of countries under conditions of joint production and fixed schedules. When the demands for bilateral trade are balanced our model nests the traditional trade theory assumption of symmetric trade costs. But when the demands for bilateral trade are imbalanced[9], these specific features of transport supply introduce the key dynamics and result in asymmetric equilibrium freight rates that critically depend on the bilateral trade imbalance. Intuitively, a bilateral trade imbalance implies an underutilization of the available capacity that carriers have allocated to both bilateral transport markets served on a given round trip. One may think of this capacity as a container vessel serving the U.S. export and import markets to and from China. Given the U.S. trade deficit with China, the difference in capacity utilization of this vessel across the two bilateral transport markets drives a wedge between the associated transport costs. We further explore the consequences of this finding and show that an isolated shock in one of the bilateral transport markets

[8]The model presented by the authors summarizes the standard *"backhaul problem"* developed in the transportation economics literature [Jonkeren et al., 2011].

[9]The potential sources underlying this demand imbalance are manifold and can stem from differences in technology, factor endowments, or economies of scale that lead to price differences across countries. The specification of the specific source of the comparative advantage goes beyond the scope of this study. Instead, we assume a simple quasi-linear Armington trade framework that differentiates products by country of origin and focus on the integration of a more complex transport sector. Further derivations simply differentiate between the states of balanced and imbalanced bilateral trade, taking these as given.

can cause asymmetric adjustments for both bilateral transport costs and lead to otherwise unanticipated spillover effects across the respective import and export markets.

In the transportation economics literature, this issue is referred to as the *backhaul problem*[10] and has received considerable attention mainly addressing the domestic trucking industry [Nicholson, 1958, Basemann and Daugherty, 1977, Wilson, 1987, Wilson and Beilock, 1994, Wilson, 1994, Demirel et al., 2010]. Similar to these studies, our theoretical derivations suggest large freight rate differentials in the *fronthaul* and *backhaul* transport markets[11] when facilitating heavily imbalanced trade between two trading regions. Unlike any of these studies, we integrate this model of the transport sector into a trade framework as presented by Hummels et al. [2009], where international trade costs now depend on national trade imbalances; a finding that separates our work from the majority of the previous trade and transportation literatures.

In contrast to Jonkeren et al. [2011], Behrens and Picard [2011] and Takahashi [2011], we apply our model to data on containerized trade in three different sets of transport markets facilitating trade between the U.S., Asia, and Europe. This is an important distinction to the previous literature, as our estimates, to the best of our knowledge, are the first to quantify the trade elasticity with respect to container freight rates, as well as the integration of bilateral transport costs and resulting spillover effects in the largest of all international markets. Due to the non-stationarities in our data, we explore the long-run cointegration relationships between trade and transportation that govern the theoretical supply and demand conditions of the international transport markets facilitating the bulk of international trade. The results not only support the general findings of the trade literature, but also highlight the endogeneity of bilateral transport costs in the determination of trade. Our

[10] This 'problem' is an artifact of the market structure that freight carriers face. Serving the market of transporting goods from region i to region j on a fixed round trip, automatically creates transport supply for the market facilitating trade from region j to region i. If this supply of transport in this market is not met with the demand for transport by shippers, it creates the, so-called, backhaul problem for carriers that incur the joint cost of serving the market pair ij.

[11] Following common terminology, given two transport markets served on a single round trip, the market facing higher demand is denoted as the fronthaul, while its counterpart, the market facing lower demand, is denoted as the backhaul.

findings indicate that a shock in one of the bilateral markets triggers bilateral transport cost adjustments that lead to spillover effects in both export and import industries.

Overall, the primary contributions of our study are threefold. First, we develop a theoretical model that integrates trade and transportation with an explicit representation of the joint production present in the container shipping industry. The novel results point to the integration of bilateral transport costs and provide an explanation for spillover effects across bilateral trade markets. Second, the empirical analysis of the long-run equilibrium conditions suggested by the theory provides strong evidence of the simultaneity between trade and transportation costs and highlights the long-run implications of the joint production present in the international transport industry on trade. Third, we use these findings to simulate the long-term trade effects resulting from idiosyncratic shocks to the container shipping industry and illustrate the economic significance of the resulting spillover effects via a counterfactual analysis of the Chinese ban on imported waste.

The remainder of this paper is organized as follows: In section 2, we present a theoretical model of trade and transportation. The empirical model is developed in section 3. Section 4 summarizes the data employed and indicates the considerable trade imbalances and freight rate differentials present in the international container shipping industry. Section 5 contains the empirical results which are generated from panel time series techniques. Section 6 provides a summary as well as conclusion and points to areas of further inquiry.

2 Theoretical Model

In this section, we develop a system of demand and supply equations that apply to the international maritime transportation markets. The demand for transportation is derived from a trade framework, and we develop a model of transport supply that reflects the simple fact that transportation firms typically haul on fixed schedules between two countries which gives rise to joint production. The result gives a complete system of trade and transportation from which the effects of unbalanced trade and policy options can be considered. Furthermore, the equilibrium conditions illustrate that the integration of trade and transportation accounts for the simultaneity between trade flows and international transportation costs and their dependence on the bilateral trade imbalance.[12] A comparative statics exercise demonstrates that this simultaneity may bias traditional gravity estimations and that the presence of joint production can alter conventional trade theory results, a finding that is complementary to analysis of Deardorff [2014].

2.1 *Demand for Transport*

To begin, we derive an expression of the demand for transport from the international trade framework in Hummels et al. [2009]. In this model of trade, each country, j=1,2,...,M, is composed of one representative consumer. Preferences of each representative consumer take a quasi-linear form and are expressed over a homogeneous numeraire commodity and a variety of a good that is differentiated by national origin, as in Armington [1969]. Following Hummels et al. [2009], we assume that the supply of a differentiated product is produced in a perfectly competitive sector that exhibits constant returns to scale and requires exactly p_i, the domestic sale price, units of labor to produce one unit of output. The price elasticity of demand, σ, is assumed to be constant across representative consumers and greater than one. Given these assumptions, the preferences of the representative consumer in country j can be expressed by the following utility function

$$U_j = q_{0j} + \sum_{i=1}^{M} q_{ij}^{(\sigma-1)/\sigma} \quad \forall j = 1, .., M, \tag{1}$$

where country j's consumption of the numeraire commodity is given by q_{0j} and the consumption of a particular variety sourced from country i is given by q_{ij}.

[12] The simultaneity, here, refers to the joint determination of bilateral trade and transport costs in the partial equilibrium theory we develop. Integrating the round-trip model of transport into the trade framework yields this endogeneity.

The price of the numeraire is normalized to one and it is assumed that this good can be traded at no cost. In contrast, the domestic sale price of a variety from country i is represented by p_i and taken as given by carriers. Given the facts that each representative consumer has a taste for variety[13] and goods are differentiated by origin, there is an incentive for trade, and trade between countries gives rise to the international transportation markets. Indeed, trade costs in the form of freight rates become a determinant of the equilibrium. And, a complete model incorporates the transportation supply to allow the equilibrium transport rates to be endogenously determined along with trade. In fact, given that each country engages in trade, the import price, p_{ij}, of a variety from country i paid by the representative consumer in country j includes per-unit transportation costs, f_{ij}, and the *ad valorem* trade costs, $\tau_{ij} \geq 1$, in addition to the sale price, p_i. That is, $p_{ij} = p_i\tau_{ij} + f_{ij}$, where the transport and *ad valorem* trade costs, such as tariffs, are taken as given by each representative consumer.[14]

Utility is maximized by each representative consumer with respect to their budget constraint. The solution to this constrained optimization problem gives the imported quantities by country j from each country i. These imports also represent the demand for transport from each country i to country j and are given by the following expression;

$$q_{ij} = \left[\frac{\sigma}{\sigma - 1}(p_i\tau_{ij} + f_{ij})\right]^{-\sigma} \quad \forall i, j = 1, .., M, i \neq j. \tag{2}$$

Of course, this expression for the demand of transport holds for any two countries i and j engaged in bilateral trade and naturally creates the transport market pair ij for each carrier facilitating trade from country i to country j and vice versa. It is important to make note

[13]The marginal utility received from each variety i approaches infinity as consumption of that variety goes to zero. Therefore, each consumer prefers at least a small amount of each variety to maximize utility and hence, each consumer has a taste for variety.

[14]This type of specification, where trade costs include both an iceberg trade cost component as well as a trade specific cost component, has been utilized by Feenstra and Romalis [2014] and is consistent with work by Hummels and Skiba [2004]. In this study, the authors point out that transport costs are more accurately modeled as unit-specific rather than *ad valorem* or iceberg trade costs, as first introduced by Samuelson [1954]. The theoretical results we derive hold irrespective of the inclusion of the *ad valorem* trade cost component.

of the fact that transport demands do not have to be equal to one another. In fact, trade flows are rarely equal. Most often country i is a net exporter to country j. The presence of such trade imbalances is particularly true for containerized cargo flows and implies that the demands for transportation in the market pair ij are typically imbalanced.[15] Following common terminology the transport market served on a round trip facing higher demand is denoted as the *fronthaul*, while its counterpart, the transport market facing lower demand, is denoted as the *backhaul*.[16]

Of course, this simple theoretical framework abstracts from some of the realities we observe in international markets. First, this theory suggests that bilateral trade imbalances arise due to intra-industry differentiation and predetermined cost differences across countries. Alternative sources of trade imbalances arising from inter-industry trade surely influence aggregate bilateral disparities between a country's exports and its imports, such as the U.S. trade deficit with China, but do not change the fact that international carriers serving these markets face the resulting transport demand imbalances. A model of trade motivated by the comparative advantage arising from technological differences, varying factor endowments, or economies of scale, for example, would impose a more sophisticated structure on the supply side of the traded products and provide alternative explanations for the existence of trade imbalances. At the same time, however, it would also unnecessarily complicate the model and add little insights in terms of the transport cost adjustments in response to the presence of these bilateral trade imbalances; the primary focus of our study. As such, the exact specification of the supply-side of traded products goes beyond the scope of this paper.

Second, this simple Armington framework implies that any imbalance observed in the trade of differentiated products must be offset by the exchange of the homogeneous product, which is traded without incurring any transport cost. As such, one should view the facilitation of the traded homogeneous product as a separate transportation industry operating

[15] It is possible, of course, to encounter situations where overall trade may be balanced, while containerized trade flows remain imbalanced due to the varying trade composition.

[16] Therefore, by definition, fronthaul and backhaul depend on the trade imbalance between two regions rather than the direction of trade flow or the starting point of a round trip.

at significantly lower, zero-valued costs than the transport sector handling differentiated products. The separation of these two industries implies that carriers specializing in the facilitation of differentiated products can face the imbalances in the demand for transport, albeit the fact that aggregate bilateral trade (including the homogeneous product) is balanced. Realistically, the homogeneous product may represent bulk shipments of oil or grain, which are shipped at much lower per unit rates than the highly imbalanced containerized trade of higher-value commodities, including, for example, a number of differentiated products, such as textiles, appliances, or furniture. Further developing our theory, we focus on the transport sector shipping differentiated products at non-trivial, non-zero-valued transportation costs.[17]

2.2 Supply of Transport

As such, the theoretical and empirical analyses specifically apply to containerized traffic between regional pairs and focus on the overall effect of transportation costs on trade flows and imbalances under the dynamics of joint production. More formally, to facilitate bilateral trade from country i to country j and vice versa, each carrier allocates capacity, K, to transport market pair ij and offers transport supplies, $Q_{ij} \leq K$ and $Q_{ji} \leq K$, to each transport market, respectively. The provision of capacity to the market pair results in available capacity in both transport markets. As such, the costs of allocating capacity are inseparable joint costs leading to the joint production concerning these transport supplies. When the demands for the joint transport supplies are imbalanced, adherence to strict schedules prohibits the allocation of search and/or waiting time for additional cargo[18] and forces carriers to adjust transport supplies accordingly. In equilibrium, this results in transportation costs

[17]An alternative framework directly accounting for the presence of trade imbalances has been developed by Dekle et al. [2007]. The integration of the transport sector in this model of trade and derivation of the equilibrium freight rates is non-trivial and an important area of future inquiry that goes beyond the scope of this paper.

[18]Interviewing several industry insiders, including port officials and freight forwarders, it was pointed out that container vessels, with the exception of extreme circumstances, adhere to strict schedules and that carriers operate on round trips staggering the vessels they deploy, in order to offer more frequent service.

that adjust to the existing demand imbalance.[19] These market frictions resulting from the joint production and tight schedules introduce the key dynamics that separate this theoretical model of a transport sector from the majority of the previous work in the trade literature and extend the model developed by Hummels et al. [2009].

We model the international shipping industry to exhibit market power. To accommodate this feature of the industry and following the derivation by Hummels et al. [2009], the transport sector is modeled as an oligopoly consisting of $l = 1, ..., N$ symmetric carriers competing in Cournot fashion. Extending the given model, we assume that each carrier, l, serving the transport market pair ij facilitates a portion of bilateral trade, q_{ij} and q_{ji}, from county i to country j and vice versa and has a round trip cost structure that is twofold. In particular, similar to Wilson [1994] and Wilson and Beilock [1994], each carrier faces market specific access costs, a_{ij}, such as additional fuel or terminal costs, for shipping one unit of a variety from country i to country j. In addition, each carrier's technology is further defined by the previously mentioned joint costs, $JC(K^l)$, with $JC(0) = 0$ and $\frac{\partial JC(K^l)}{\partial K^l} > 0$. These costs of providing capacity include, for example, labor, maintenance and repairs, or insurance costs that are not differentiable between the individual transport markets and can be viewed as, quite simply, the costs of traveling between the two locations.[20] Therefore, each carrier's round trip costs can be expressed as follows:

$$C^l = a_{ij}Q^l_{ij} + a_{ji}Q^l_{ji} + JC(K^l) \; \forall l = 1, ..., N \; and \; i, j = 1, ..., M, \; i \neq j. \tag{3}$$

[19]Individual carriers may serve multiple locations on a single round trip or take advantage of hub and spoke shipping networks to reduce the backhaul problem. However, as the cargo flows depicted in Figures 3(a), 3(c), and 3(e) reveal, severe aggregate traffic imbalances prevail despite the potential for such strategies. Thus, for expositional purposes, we assume that each carrier serves only two regions with each round trip. Generalization to multiple locations is straight forward.

[20]A simplified version of this cost structure has been developed by Behrens and Picard [2011]. In their study, the authors abstract from the differentiation between per unit and capacity costs and, instead, assume that carriers face a given round-trip cost that simply depends on the larger of the two bilateral transport supplies. While this abstraction produces a more elegant derivation, it has the considerable drawback of producing unrealistic zero-valued freight rates in backhaul markets when bilateral trade is imbalanced. While our specification requires a more complex cost structure, it is arguably more realistic and avoids this extreme result of freely transported products in backhaul markets, such as U.S. exports to China facing more than $800 in average freight charges per container.

Given this cost structure, each carrier simultaneously chooses the profit maximizing transport capacity, K^l, and optimal supplies of transport[21], Q^l_{ij} and Q^l_{ji}, that are offered to each market on a given round trip.[22] Each carrier's profit from a given round trip from country i to country j and vice versa can be written as

$$\begin{aligned} &\max_{K^l, Q^l_{ij}, Q^l_{ji}} \Pi^l = f_{ij} Q^l_{ij} + f_{ji} Q^l_{ji} - C^l \quad \forall l = 1, ..., N \text{ and } i, j = 1, ..., M,\ i \neq j \\ &\text{subject to } K^l \geq Q^l_{ij},\ K^l \geq Q^l_{ji}. \end{aligned} \tag{4}$$

Solving each carrier's constrained profit maximization problem results in three $Nx1$ vectors of first-order conditions, along with the standard Kuhn-Tucker conditions, that can be represented as follows;

$$f_{ij} + Q^l_{ij} \frac{\partial f_{ij}}{\partial Q^l_{ij}} - a_{ij} - \lambda_1 \leq 0 \qquad \text{with} = \text{if } Q^l_{ij} > 0 \qquad \forall l = 1, ..., N \tag{5a}$$

$$f_{ji} + Q^l_{ji} \frac{\partial f_{ji}}{\partial Q^l_{ji}} - a_{ji} - \lambda_2 \leq 0 \qquad \text{with} = \text{if } Q^l_{ji} > 0 \qquad \forall l = 1, ..., N \tag{5b}$$

$$-\frac{\partial JC(K^l)}{\partial K^l} + \lambda_1 + \lambda_2 \leq 0 \qquad \text{with} = \text{if } K^l > 0 \qquad \forall l = 1, ..., N \tag{5c}$$

$$K^l \geq Q^l_{ij}, \qquad \lambda_1 \geq 0, \qquad (K^l - Q^l_{ij})\lambda_1 = 0 \tag{5d}$$

$$K^l \geq Q^l_{ji}, \qquad \lambda_2 \geq 0, \qquad (K^l - Q^l_{ji})\lambda_2 = 0. \tag{5e}$$

The first-order conditions with respect to transport supplies, given by Equations (5a) and

[21] Alternatively, the carriers' decision process may be modeled as a two stage Cournot game, where carriers first decide on capacity and then offer transport supplies. While this assumption is sensible given the five year lead time to build a vessel, it is undermined by the significant amount of temporarily chartered vessels used by major carriers to supplement currently owned capacity. According to the Review of Maritime Transport published by the United Nations Conference on Trade and Development [UNCTAD, Secretariat, 2010], about 50% of the available capacity offered by the top 20 liner companies was chartered in 2009. Given this mixture of owned and chartered capacity, we believe that a one stage game of carriers, each simultaneously choosing capacity and transport supplies, is most appropriate.

[22] Of course, the dimensionality of each carrier's optimization problem can be extended to include a variety of alternative issues present in the international shipping industries. For example, carrier costs may be modeled as dependent upon the actual port of entry or uncertainty concerning the reliability of the hinterland transportation network. Although these issues are important, they go beyond the scope of this paper and would extend the theoretical model to a level of disaggregation that is not available in the data. Therefore, we abstract from issues of uncertainty and limit the theoretical analysis to a one port per country model.

(5b), can be seen as each carrier's market access conditions indicating that marginal revenues in either transport market must equal or exceed access costs for a given market to be served. In addition to that, each carrier's first-order condition with respect to allocated capacity (Equation (5c)) can be interpreted as the service condition. That is, given the fact that the Kuhn-Tucker multipliers, λ_1 and λ_2, can be thought of as the shadow prices that determine the value of an additional unit of transport supply in the respective transport markets, equation (5c) states that a carrier serves a given market pair only if the total value of an additional unit of transport supply in either market covers the marginal joint costs for providing the necessary capacity.

In order to solve for the equilibrium transport supplies and capacity allocation, we impose the transport market clearing conditions that demand for transport must equal the supply of transport in each market. These market clearing conditions can be represented by the following equations;

$$q_{ij} = \sum_{l=1}^{N} Q_{ij}^{l} \tag{6a}$$

$$q_{ji} = \sum_{l=1}^{N} Q_{ji}^{l}. \tag{6b}$$

Combining the demand for transport given by equation (2), the first-order and Kuhn-Tucker conditions given by (5a)-(5e) and the market clearing conditions represented by equations (6a) and (6b), an equilibrium solution involving multiple possible cases can be obtained. While the details of the derivation are fairly standard, there are a few aspects of the set of solutions that are important to point out.

First, given our model, it can be shown that at least one of the capacity constraints, $K^l \geq Q_{ij}^l$ and/or $K^l \geq Q_{ji}^l$, must be binding in any equilibrium solution. This implies that any solution to our static model is characterized by full capacity utilization in at least one of the two transport markets. While additional considerations, such as the time that it takes to build a container vessel to adjust capacity, may introduce market frictions that lead to non-binding capacity constraints in the short-run, full utilization of allocated capacity is a sensible feature for any of the long-run equilibrium cases derived from our model.

Second, the set of potential equilibrium cases includes solutions where optimal transport supplies and international trade are zero. These scenarios can arise when marginal joint and/or access costs are prohibitively high for the transport market pair or for either one of the individual transport markets. For the purposes of this study, the remaining analysis solely focuses on cases where equilibrium transport supplies and international trade are positive in both transport markets.

Third, equilibrium solutions involving positive unilateral or bilateral international trade exist and can be derived in symmetric pairs that simply interchange the i and j notation. Thus, without loss of generality, we treat the transport market facilitating trade from country i to country j as the fronthaul and the transport market facilitating trade from country j to country i as the backhaul for the remainder of the analysis.

2.3 Equilibrium Considerations

Given non-prohibitive access and marginal joint costs in fronthaul and backhaul transport markets, the solution to the model has to distinguish between the balanced and imbalanced trade cases. Naturally, the consideration of whether the balanced or imbalanced trade equilibrium arises, heavily depends on the imbalance concerning the demands for transport. Given equation (2), this demand imbalance can be represented and rewritten as follows;

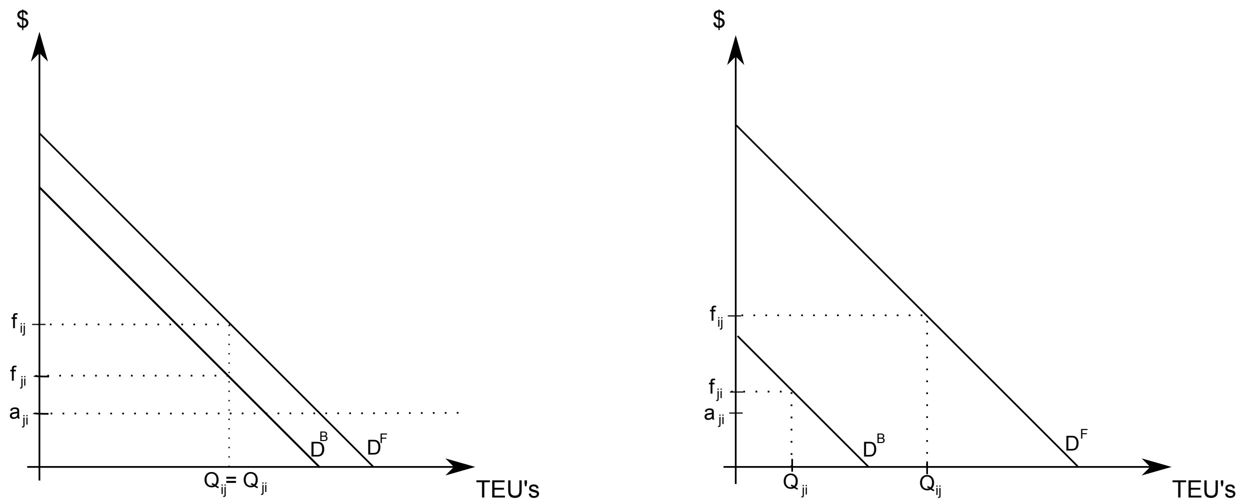
$$q_{ij} \geq q_{ji} \implies p_j\tau_{ji} - p_i\tau_{ij} \geq f_{ij} - f_{ji}, \tag{7}$$

As equation (7) shows, the size of the trade imbalance depends on the difference in domestic sale prices as well as the endogenously adjusting freight rate differential. As has been shown in trade literature, price differences, or in other words a comparative advantage, can arise under various assumptions, including for example technology differences, variation in factor endowments, or economies of scale. Irrespective of the exact source of the comparative advantage, we focus our analysis on the implications arising in the presence of these domestic sale price differences. Intuitively, small differences in the bilateral demands for transport, due to small sale price variations across country i and j, may allow carriers to choose equal transport supplies that maximize capacity utilization in both transport markets. The resulting equilibrium freight rate differential must offset any price differences, so that bilateral trade balances.

Large imbalances concerning the bilateral demands for transport caused by substantial differences in sale prices between two countries, however, may force carriers to choose asymmetric transport supplies with excess capacity in the backhaul market. The resulting equilibrium freight rate differential does not offset the sale price variation and leads to imbalanced bilateral trade. In fact, it can be shown that a balanced trade equilibrium only arises when $p_j\tau_{ji} - p_i\tau_{ij} \in \left(a_{ij} - a_{ji} - \frac{\partial JC(K^l)}{\partial K^l}, a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right)$, whereas an imbalanced trade equilibrium, where exports from country i to country j exceed exports from country j to country i, results when $p_j\tau_{ji} - p_i\tau_{ij} > \left(a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right)$.[23] Both of these scenarios can be represented graphically and are depicted by Figures 2(a) and 2(b).

Figure 2(a) demonstrates the balanced trade case. In this scenario, the difference between fronthaul demand, D^F, and backhaul demand, D^B, is rather small. Given this small difference in demands for transport, each carrier's optimal choice leads to symmetric transport supplies, $Q^l_{ij} = Q^l_{ji}$, which in turn leads to asymmetric equilibrium freight rates, $f_{ij} \neq f_{ji}$. As Figure 2(a) shows, the size of the potential freight rate differential depends on the actual imbalance of the demands for transport. Furthermore, Figure 2(a) illustrates that this differential between freight rates mitigates the difference in sale prices (inclusive of *ad valorem* trade costs), effectively equalizing the equilibrium demands for transport, and thus, leading to balanced bilateral trade. If we, instead, maintained the traditional symmetric trade cost assumption, while allowing sale prices to vary across countries, Figure 2(a) shows that this

[23]Due to symmetry, trade is also imbalanced when $p_i\tau_{ij} - p_j\tau_{ji} > \left(a_{ji} - a_{ij} + \frac{\partial JC(K^l)}{\partial K^l}\right)$. In this case, country j becomes the net exporter and the transport market ji becomes the fronthaul.



(a) Balanced Trade

(b) Unbalanced Trade

Figure 2: Linkages between the Balance of Trade and Transportation Cost Differentials

symmetry would impose empty containers in the backhaul transport market that are inconsistent with balanced trade. This highlights an important result of the theoretical model, which states that actual bilateral trades are only balanced when freight rates are free to endogenously adjust to the demand imbalances and are allowed to be asymmetric between two trading countries.

In contrast, Figure 2(b) demonstrates the unbalanced trade case, where fronthaul demand, D^F, is much larger than backhaul demand, D^B. Given such a large difference in demand stemming from a large sale price variation across countries, each carrier optimizes by choosing asymmetric transport supplies, $Q^l_{ij} \neq Q^l_{ji}$. This, of course, results in imbalanced bilateral trade in the presence of potentially asymmetric freight rates, $f_{ij} \geq f_{ji}$. Next, we present the equilibrium solutions differentiating between the balanced and imbalanced trade cases more formally.

2.3.1 Case 1: Balanced Trade

For small transport demand imbalances, each carrier's equilibrium supplies of transport for a given round trip from country i to j and vice versa and the resulting equilibrium transportation rates can be derived as follows[24]:

$$K^l = Q^l_{ij} = Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma N}{2(\sigma N-1)}\frac{\sigma}{\sigma-1}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij} + p_j\tau_{ji}\right)\right]^{-\sigma} \tag{8a}$$

$$f_{ij} = \frac{\sigma N}{2(\sigma N-1)}\left[a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_j\tau_{ji}\right] + \frac{2-\sigma N}{2(\sigma N-1)}p_i\tau_{ij} \tag{8b}$$

$$f_{ji} = \frac{\sigma N}{2(\sigma N-1)}\left[a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right] + \frac{2-\sigma N}{2(\sigma N-1)}p_j\tau_{ji}. \tag{8c}$$

2.3.2 Case 2: Imbalanced Trade

Solving the model when the demands for transport are strongly imbalanced yields the following expressions for each carrier's equilibrium supplies of transport and capacity allocation, as well as the respective equilibrium transportation rates for a given round trip from country i to j and vice versa, where transport market ij is considered the fronthaul:

$$K^l = Q^l_{ij} = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right)\right]^{-\sigma} \tag{9a}$$

$$Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ji} + p_j\tau_{ji}\right)\right]^{-\sigma} \tag{9b}$$

$$f_{ij} = \frac{\sigma N}{\sigma N-1}(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l}) + \frac{1}{\sigma N-1}p_i\tau_{ij} \tag{9c}$$

$$f_{ji} = \frac{\sigma N}{\sigma N-1}a_{ji} + \frac{1}{\sigma N-1}p_j\tau_{ji}. \tag{9d}$$

Thus, in the balanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of the transport market pair ij facilitating balanced bilateral trade from country i to j and

[24]Note that the derivation of the optimal supplies of transport and resulting equilibrium freight rates relies on the symmetry of carriers.

vice versa is described by equations (2) and (8a)-(8c). Whereas, in the imbalanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of the transport market pair ij facilitating imbalanced bilateral trade from country i to country j and vice versa is described by equations (2) and (9a)-(9d). Both equilibrium solutions exhibit several key features that are present when trade is facilitated by an international transportation industry that is subject to the backhaul problem.

While marginal access costs play a role in the determination of transport supplies and equilibrium freight rates regardless of the demand imbalance facing carriers, the allocation of marginal joint costs is heavily dependent upon this imbalance. That is, in the balanced trade case, equations (8a)-(8c) show that marginal joint costs matter to the determination of both fronthaul and backhaul equilibrium transport supplies as well as freight rates. In contrast, equations (9a)-(9d) demonstrate that, in the imbalanced trade case, marginal joint costs only matter to the determination of the equilibrium fronthaul transportation supply and the equilibrium fronthaul freight rate.

Overall, the above system of equilibrium equations provides the basis for our empirical work. It describes the transport market equilibrium facilitating bilateral trade on a round trip between two countries and allows for comparative statics that are commonly done in the trade literature. Some of these comparative statics are highlighted in the following subsection and inform the empirical analysis of the theoretically suggested correlations between trade, transport costs and the additional determinants.

2.4 Comparative Statics

Based on the balanced and imbalanced bilateral trade equilibrium cases, we could derive a variety of elasticities pertaining to trade and transport costs. For the purposes of this study, the consequences of the endogeneity and integration of these bilateral transport costs is of particular interest. To gain insights into these specific implications, we derive the elasticities of fronthaul and backhaul trade as well as freight rates with respect to country i's domestic sale price and compare these to the elasticities arising from rather traditional versions of our model. The results of these comparative statics are presented in Table 1 and provide key insights into the issues arising from the simultaneity, or in other words joint equilibrium determination, of trade and transport costs as well as the integration of these bilateral freight rates. This integration of bilateral freight rates can be illustrated by the fact that in balanced case both fronthaul and backhaul transport costs hinge on the domestic sale prices of both countries. Intuitively, an export supply shock in country i will spill over into its import market, due to the fact that carriers will reallocate transport costs across the two markets and thereby integrate export and import transport costs.

In column 1 of Table 1, we present the elasticities resulting from the naive specification taking the transport sector as exogenous and assuming that carriers, and thus freight rates, are unresponsive to changes in trade. Given this naive specification, only country i's exports negatively respond to a rise in country i's domestic sale price. All other variables remain constant. Hummels et al. [2009] extend this theory by modeling the transport sector facilitating unilateral trade. Carriers facilitate trade from country i to country j, but ignore the profit opportunities of facilitating cargo on the backhaul from country j to country i. The result is an endogenously adjusting freight rate charged on country i's exports that rises with an increase in country i's domestic sale price.[25] As shown by column (2), backhaul trade, however, remains unaffected and no spillover effects can be explained with this framework.

In contrast to these findings, the elasticities derived from our model, integrating an international transport sector that facilitates both exports and imports of country i, are distinctly different from the alternative specifications. In the balanced bilateral trade case, presented in column (3), country i's exports and imports shipped in the fronthaul and backhaul markets respond to a change in country i's domestic sale price. Intuitively, an

[25]Naturally, a more general equilibrium framework, that explicitly models the supply side of the differentiated products, may allow feedback effects arising from changing transport costs. That is, producers of variety i may adjust their supply in response to the changing freight rates. While this extended feature would slightly alter the magnitude of the derived elasticities, it would not change the key facts illustrated in Table 1. That is, the careful theoretical treatment of an endogenously adjusting transport sector significantly alters the traditional trade elasticity estimates derived from more restrictive theoretical frameworks.

Table 1: Comparative Statics - Trade and Freight Rate Elasticities

Elasticities with respect to p_i	**Traditional**	**Endogenous**	**Endogenous & Integrated**	
			Balanced	Imbalanced
	(1)	(2)	(3)	(4)
$\frac{\partial q_{ij}}{\partial p_i}\frac{p_i}{q_{ij}}$	$-\sigma\frac{p_i\tau ij}{p_i\tau_{ij}+f_{ij}}$	$-\sigma\frac{p_i\tau ij}{a_{ij}+p_i\tau_{ij}}$	$-\sigma\frac{p_i\tau ij}{a_{ij}+a_{ji}+JC'+p_j\tau_{ji}+p_i\tau_{ij}}$	$-\sigma\frac{p_i\tau ij}{a_{ij}+JC'+p_i\tau_{ij}}$
$\frac{\partial f_{ij}}{\partial p_i}\frac{p_i}{f_{ij}}$	0	$\frac{1}{\sigma N-1}\tau_{ij}$	$\frac{2-\sigma N}{2(\sigma N-1)}\tau_{ij}$	$\frac{1}{\sigma N-1}\tau_{ij}$
$\frac{\partial q_{ji}}{\partial p_i}\frac{p_i}{q_{ji}}$	0	0	$-\sigma\frac{p_i\tau ij}{a_{ij}+a_{ji}+JC'+p_j\tau_{ji}+p_i\tau_{ij}}$	0
$\frac{\partial f_{ji}}{\partial p_i}\frac{p_i}{f_{ji}}$	0	0	$\frac{\sigma N}{2(\sigma N-1)}\tau_{ij}$	0

increase in country i's sale price, leads to a decline in fronthaul demand for transport from country i to country j and in turn, induces carriers to reduce transport supplies not only in the fronthaul, but also in the backhaul market, in order to keep bilateral trade balanced. Given the reduction in fronthaul demand and an unchanged backhaul demand for transport, this reduction in bilateral transport supplies results in a spillover effect that not only leads to a decline in the fronthaul freight rate[26], but also a rise in the backhaul freight rate. Thus, idiosyncratic shocks, such as a unilateral price change or ban on waste imports, leading to changes in the demand imbalance for transport are found to cause spillover effects between bilateral export and import markets.

Naturally, in the imbalanced bilateral trade case, presented in column (4), the derived elasticities mirror the results from Hummels et al. [2009], where only the fronthaul market is affected. While the elasticities of the fronthaul freight rates with respect to the origin sale price are identical across models, the elasticities of trade vary between the two frameworks. Ignoring the joint production present in the container shipping industry inflates the theoretical elasticity of trade, which, in our model, is subject to the marginal joint costs arising

[26]There exists an extreme case where the rise in country i's sale price, in fact, triggers a rise in the fronthaul freight rate charged on country i's exports. This case can only arise in a monopolistic setting where the elasticity of substitution is rather small, or in other words less than two.

from serving the bilateral export and import market pair.

Overall these comparative statics illustrate that a standard model of trade, extended to account for the joint production present in the international transportation industry, can shed light on otherwise unanticipated outcomes. When trade is rather balanced, our model predicts that a trade shock pertinent to country i's exports also leads to a spillover effect on country i's imports. This result compliments and extends the finding by Deardorff [2014] who shows that the presence of unit-specific transport costs can distort traditional trade theory results. Lastly, an important caveat and area for future inquiry to point out is the fact that the partial equilibrium framework we have developed here abstracts from more general equilibrium considerations, such as wage and hence terms of trade adjustments. While these alterations would not change the qualitative conclusions drawn from the elasticities presented in Table 1, it is certainly plausible that there are significant quantitative effects on the derived spillovers.

3 Empirical Model

Based on the partial equilibrium conditions (2) and (8a)-(8c) as well as (9a)-(9d), we develop the empirical model to test whether the theoretical simultaneity between trade and transport costs and the presence of joint production holds in the data. The estimation is, therefore, focused on the demand for transport as well as the fronthaul and backhaul pricing relations described by the static partial equilibrium framework. Since the data are non-stationary quarterly time series observations that exhibit the existence of panel cointegration across the three market pairs in the sample[27], our identification strategy employs time series techniques to estimate the static long-run equilibrium relations implied by the structural model.[28] Since traditional panel data techniques may render spurious regression results in this scenario, we

[27]Multiple panel unit-root and cointegration tests were applied to the data. The results are reported in Tables 8 and 9 in the Appendix and speak to the non-stationarities of the data, as well as the existence of panel cointegration relations.

[28]As noted by Hamilton [1994], the potential for spurious regressions due to unit roots is accounted for by the existence of a cointegration relation.

develop the empirical model to reflect the use of panel cointegration methods that unmask the structural equations underlying the theoretical long-run partial equilibrium model. Indeed, as Hamilton [1994] states:

> *"Cointegration can be viewed as a structural assumption under which certain behavioral relations of interest can be estimated (...)"* [Hamilton, 1994, p. 589]

First, we consider the demand equation. As equation (2) indicates, the demands for transportation in market pair ij are given by the quantity of containerized bilateral trade facilitated from region i to region j and vice versa and are a function of sale prices, *ad valorem* trade costs and unit-specific transport costs. Furthermore, the theoretical model suggests that there are no inherent differences between fronthaul and backhaul transport markets concerning the dependence of trade on these determinants. Thus, we estimate the demand for transport via a single equation, where the quantity of transport demanded from region i to j is denoted by q_{ijt}. The cross-sectional dimension of a trade route is indicated by ij, while the time series dimension of the data is given by t. The domestic sale price is denoted p_{it}, whereas unit-specific transport costs are given by the container freight rate, f_{ijt}, that is charged to facilitate trade from region i to region j.

To capture the unobservable characteristics and control for the heterogeneity between trade routes, a transport market specific fixed effect, α_{ij}, is included in the model. This follows the fixed effect specification suggested by Cheng and Wall [2005] and captures time-invariant *ad valorem* trade costs, τ_{ij}.[29] Panel cointegration tests developed by Pedroni et al. [1999] and Pedroni [2004] are used to allow for this heterogeneity across panels and inform about the necessity of market pair specific time trends. Based on the test results presented in Table 9 in the Appendix, we do not integrate a market pair specific time trend in the

[29] Other empirical trade studies, particularly those estimating gravity models, have included a variety of *ad valorem* trade cost proxies. According to Head and Mayer [2013], the traditional proxies include dummy variables for contiguity, common official language, colonial linkages and Regional Trade Agreements (RTA's) as well as Free Trade Agreements (FTA's). Due to the fact that the cross-sectional dimension of the data is at a supranational level, these country-specific effects cannot be separately identified in the empirical model. To the extent that *ad valorem* trade costs differ across supranational geographic regions, however, time-invariant *ad valorem* trade costs are captured by the market pair specific fixed effects.

empirical model of the demand for transport.

Lastly, empirical studies of trade tend to suggest that aggregate income plays a central role in the determination of trade and thus, the international demand for transport. Because of the partial equilibrium nature and quasi-linear demand structure of our theoretical model, however, this income effect is suppressed in Equation (2). While useful for the tractability of the theoretical derivations when integrating a complex transport sector, we abstract from this simplified structure empirically. Instead, we follow the vast majority of the trade literature and model trade as a function of aggregate income, controlled for via exporter and importer real GDP and denoted by y_{it} and y_{jt}, respectively.

The estimation of the panel cointegration relations in a heterogeneous panel is based on the Panel Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS) estimators developed by Pedroni [2001] and Pedroni [2000], respectively. In addition to the previously discussed variables, the DOLS estimator also includes lagged and lead terms of the first differences of all the right hand side variables to control for the dynamic properties of the data. More specifically, these terms, summarized in the vector Δx_{ijt}, control for the endogenous feedback effect that is present between international trade and freight rates as well as the other determinants of trade. Consequently, the theoretically motivated empirical specification of the demand for transport becomes

$$q_{ijt} = \alpha_{ij} + \beta_1 f_{ijt} + \beta_2 p_{it} + \beta_3 y_{it} + \beta_4 y_{jt} + \sum_{s=-S}^{S} \Theta \Delta x_{ijt+s} + \epsilon_{ijt}, \tag{10}$$

where containerized trade, measured in the number of twenty-foot containers shipped from country i to country j, is given by q_{ijt}, freight rates are given by f_{ijt}, and the domestic sale price is represented by p_{it}. Exporter and importer income are given by y_{it} and y_{jt}, whereas route-specific fixed effects are captured by α_{ij}. While all of these variables are in logged form, S indicates the maximum number of first-differenced lags and leads included in the model. The random error component is denoted by ϵ_{ijt}. The cointegration relation and coefficients of interest are described by β_1-β_4. Accurately estimating the cointegration relation underlying this demand equation renders the residual stationary and implies that any variation from this long-run static equilibrium relationship is only temporary.[30]

While Equation (10) vaguely resembles the reduced-form gravity equation from the trade literature, it drastically varies from the structural gravity models summarized by Head and Mayer [2013] and should not be interpreted as such. Several of the commonly included control variables and fixed effects, to capture the multilateral resistance terms [Anderson and van Wincoop, 2003] for example, are excluded from the empirical specification. More appropriately, Equation (10) can be interpreted as a panel cointegration estimator that models trade as a function of the underlying cointegration relation critically dependent on the endogenously determined freight rates, sale prices, and aggregate exporter and importer income. Further, it incorporates the respective first-differenced lags and leads of the right-hand side variables to control for the endogenous feedback effects and renders the trade elasticities of interest unbiased [Hamilton, 1994, Pedroni, 2000, 2001].

To complete the empirical model and demonstrate the simultaneity between trade and transportation as well as test for the potential transport-cost-induced spillover effects across a country's exports and imports, we develop the empirical specifications of the theoretical pricing relations, as suggested by equations (8b) and (8c) as well as (9c) and (9d), next. Following the theoretical model, we consider two equilibrium pricing relations distinguishing between fronthaul and backhaul transport markets. The left-hand side variables are given by the international container freight rates, f_{ijt} and f_{jit}. Each of these transport costs is modeled as a function of the respective origin sale prices, p_{it} and p_{jt}, as well as access costs for shipping from country i to country j and vice versa, a_{ij} and a_{ji}. We control for these access costs via crude oil prices, denoted by oil_{ijt}. Reflective of a voyage's fuel costs, these

[30] In the gravity literature, Santos Silva and Tenreyro [2006] point out that log transformations require the assumption of a log-normal error term and, furthermore, require the observations with zero trade flows to be excluded from the estimation sample. Since the sample used in this study includes time series observations on only three market pairs comprised of trading regions at a supranational level, there are no zero valued trade flows contained in the dataset. Furthermore, the existence of a cointegration relation renders the error term stationary which is the critical assumption for the group-mean panel estimators employed in this study.

crude oil prices significantly affect the per unit transport costs of shipping a container from region i to region j and vary regionally.[31] While it is expected that an increase in the price of crude oil raises access cost and thus, increases the equilibrium freight rates, the expected effects of an increase in the respective origin sale prices are ambiguous according to theory and critically depend on the trade imbalance.

To account for this dependence on the trade imbalance, capture the role of marginal joint costs and test for the potential for spillover effects across bilateral export and import markets, we integrate the trade imbalance, δ_{ijt}, as a determinant of fronthaul and backhaul freight rates. As equations (8b) and (9c) demonstrate, marginal joint costs are a determinant of fronthaul freight rates regardless of the trade imbalance. However, equations (8c) and (9d) illustrate that the dependence of the backhaul freight rate on marginal joint costs varies between the balanced and imbalanced trade equilibrium cases. Careful consideration of the theoretical model suggests that a movement towards more balanced trade is associated with a decrease in the fronthaul freight rate, due to the reallocation of marginal joint costs away from the fronthaul and towards the backhaul transport market. In contrast, this exact reallocation, due to a greater balance between a country's exports and imports, is expected to lead to an increase in the backhaul freight rate, now covering a larger share of overall joint costs.

Again, we incorporate market pair specific fixed effects, a_{ij}, to account for the heterogeneity across market pairs and lead and lagged terms of the first-differenced right-hand side variables, denoted by the vector Δz_{ijt}, to control for the endogenous feedback effects. The cointegration tests reveal that neither of the long-run equilibrium pricing relations include a market pair specific time trend. Motivated by the theoretical pricing relations (8b) and (8c)

[31] Historically, the ports of Rotterdam and Singapore offer the lowest bunker fuel prices globally. In the U.S., the ports of Houston and New York offer these fuels at the lowest price. According to Rodrigue et al. [2017], normal daily fuel consumption ranges from 100 to 300 tons depending on vessel size and travel speed. Given bunker fuel prices of around \$400 per ton, fuel costs aggregate to over \$40,000 per day and make up a significant share of variable access costs.

as well as (9c) and (9d), this leads to the following empirical pricing relation specifications;

$$f_{ijt} = \alpha_{ij} + \gamma_1^{ij} p_{it} + \gamma_2^{ij} oil_{ijt} + \gamma_3^{ij} \delta_{ijt} + \sum_{s=-S}^{S} \Phi^{ij} \Delta z_{ijt+s} + \nu_{ijt}, \tag{11a}$$

$$f_{jit} = \alpha_{ji} + \gamma_1^{ji} p_{jt} + \gamma_2^{ji} oil_{jit} + \gamma_3^{ji} \delta_{ijt} + \sum_{s=-S}^{S} \Phi^{ji} \Delta z_{jit+s} + \nu_{jit}, \tag{11b}$$

where the error terms are represented by ν_{ijt} and ν_{jit} and the parameters of interest are given by γ_1^{ij}-γ_3^{ij} and γ_1^{ji}-γ_3^{ji} for fronthaul and backhaul transport markets, respectively.

In following sections we summarize the data before proceeding with the estimation of cointegration relations via the DOLS and FMOLS estimators.

4 Data

The data we use to estimate the parameters of the empirical model have been obtained from various sources. Gross Domestic Product and Consumer Price Index (CPI) data to control for aggregate income and domestic sale prices for the U.S., the Euro-Area and several Asian countries have been obtained from the *OECD Main Economic Indicators database*. Since the cross-sectional dimension considers trade at supranational levels (except for the U.S.), Asian GDP is controlled for via the cumulative GDP of Japan, South Korea, India, and Indonesia, while the Asian sale price is controlled for via the average CPI of Japan, South Korea, India, Indonesia, and China. Market access costs in the Trans-Pacific, Trans-Atlantic, and Asia-EU markets are given by the respective West Texas Intermediate (WTI), Brent, and Dubai crude oil prices that have been obtained from the *Federal Reserve Economic Data*.

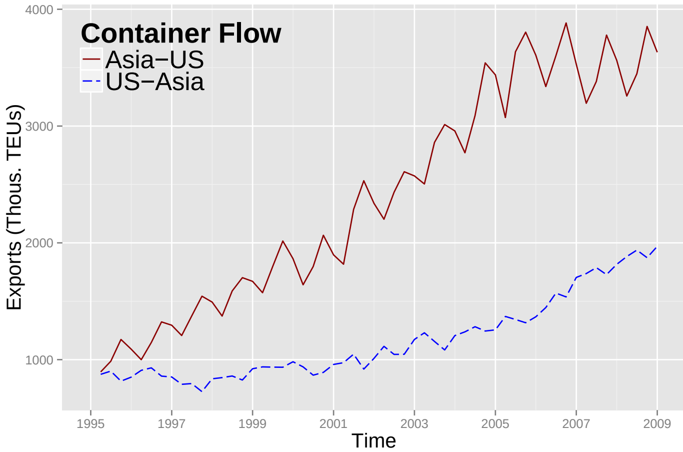
Data on the left-hand side variables, including containerized cargo flow and regional freight rates, have been obtained from *Drewry* and *Containerisation International* via the annual reports by UNCTAD, Secretariat [1979-2014], respectively. All of the data are observed at quarterly frequencies and span a time frame from the fourth quarter of 1995 to the fourth quarter of 2009. While all variables used in the estimation of the empirical model are in logged form and adjusted for seasonal variation and inflation (when applicable)[32], the seasonally unadjusted nominal level data on these variables are summarized in Tables 2 and 3.

In accordance with the theoretical model, the data have been categorized into fronthaul and backhaul transport markets between the various ij market pairs. These market pairs include the *Trans-Pacific Market* which is defined as the containerized cargo flow between the U.S. and Asia, the *Trans-Atlantic Market* defined as the containerized cargo flow between the U.S. and EU, and the *Asia-EU Market* including containerized trade flows between these two regions. The means and standard deviations of these containerized cargo flows and freight rates, listed in columns (2) and (3) of Table 2, indicate large trade imbalances and freight rate differentials in the Trans-Pacific and Asia-EU markets, as well as considerable volatility over time. The Trans-Atlantic market, however, exhibits less distinguished trade and freight rate imbalances, on average.

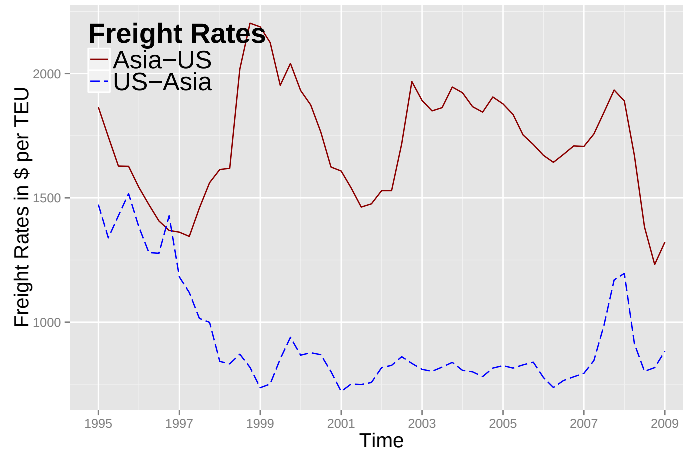
Figures 3(a)-3(f) provide additional evidence in support of these initial observations. The figures depict the unadjusted freight rates and containerized trade flows for each of the three transport market pairs. The trade imbalances present in the Trans-Pacific and Asia-EU market pairs, given by Figures 3(a) and 3(c), are large with a clearly defined net exporting region, Asia, and net importing region, the U.S. and EU, respectively. The associated freight rates, depicted in Figures 3(b) and 3(d), exhibit significant differentials that mirror the respective regional trade imbalances and draw a clear distinction between fronthaul and backhaul trade flows in these markets.

In contrast, Figures 3(e) and 3(f) show that the Trans-Atlantic market pair exhibits more modest trade imbalances where both the EU and the U.S. report temporary trade deficits and surpluses over the sample period. These switches between the net exporting and importing regions roughly coincide with switching freight rate differentials. In particular, the figures reveal roughly balanced bilateral trade between the U.S. and EU during the

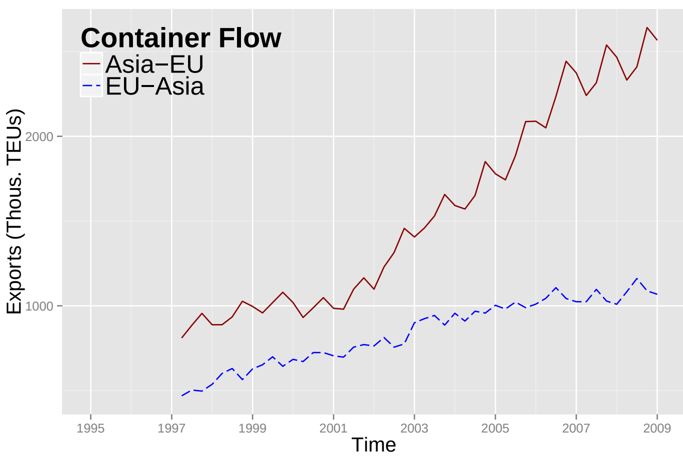
[32]Seasonal adjustments have been performed via the X11 routine.



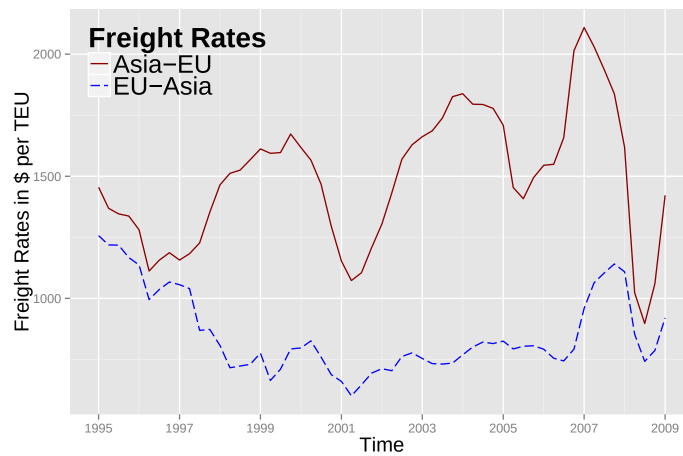
(a) Trans-Pacific Cargo Flows



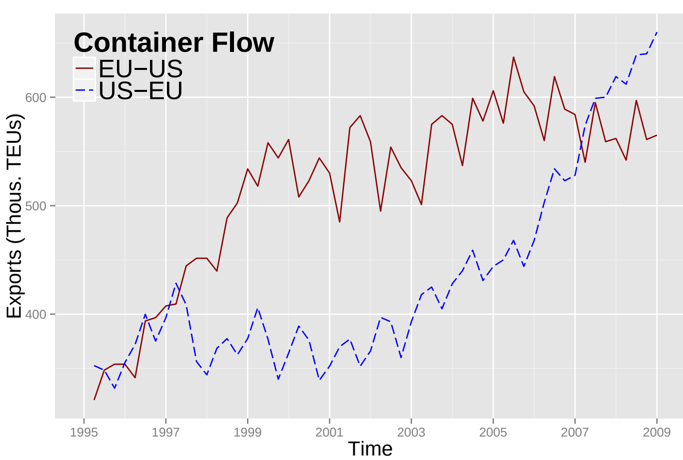
(b) Trans-Pacific Freight Rates



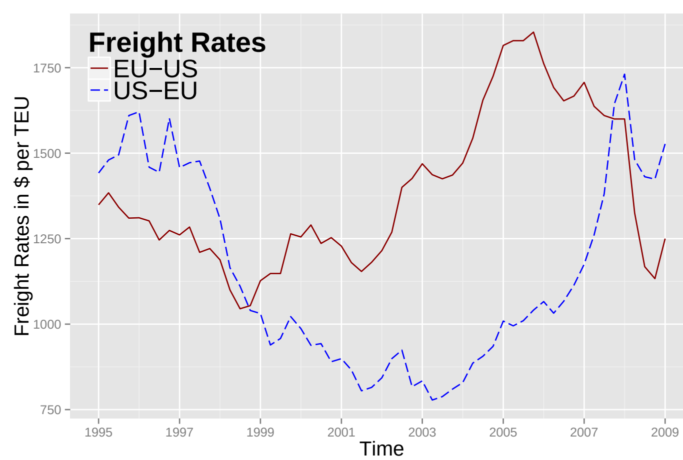
(c) Asia-EU Cargo Flows



(d) Asia-EU Freight Rates



(e) Trans-Atlantic Cargo Flows



(f) Trans-Atlantic Freight Rates

Figure 3: Trade Imbalances and Freight Rate Differentials

Table 2: Summary Statistics - Trade and Transport Costs (1995-2009)

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Qtr. Avg. Cargo Flow (Thous. TEUs)					
Fronthaul Qty: Trans-Pacific Market	56	2,412	942.4	895.1	3,883
Backhaul Qty: Trans-Pacific Market	56	1,169	352.2	726.0	1,970
Fronthaul Qty: Asia-EU Market	48	1,556	587.4	810.2	2,642
Backhaul Qty: Asia-EU Market	48	843.5	193.2	468.7	1,161
Fronthaul Qty: Trans-Atlantic Market	56	528.2	83.01	348.4	660
Backhaul Qty: Trans-Atlantic Market	56	423.3	76.45	320.8	597
Qtr. Avg. Freight Rates ($ per TEU)					
Fronthaul Rate: Trans-Pacific Market	57	1,717	226.3	1,232	2,203
Backhaul Rate: Trans-Pacific Market	57	930.8	217.0	721	1,517
Fronthaul Rate: Asia-EU Market	57	1,491	274.8	897	2,109
Backhaul Rate: Asia-EU Market	57	853.1	167.0	601	1,257
Fronthaul Rate Trans-Atlantic Market	57	1,414	219.9	1,045	1,854
Backhaul rate: Trans-Atlantic Market	57	1,117	255.6	778	1,637

The data presented in this table pertain to containerized trade and the associated freight rates between the regions of Asia, the EU, and the United States. The data are organized by regional trade relations and categorized into fronthaul and backhaul transport markets. The definition of these markets rests on the specific trade imbalance in any of these three regional trade pairs. Since the U.S. exhibits a trade deficit with Asia over the entire sample period, for example, Asian containerized exports to the U.S. represent the Trans-Pacific fronthaul market, whereas the corresponding backhaul market is given by U.S. exports to Asia. A similar categorization is reached for the Asia-EU market, where the EU runs a trade deficit with Asia over the entire sample period. For the Trans-Atlantic market, the definition of the fronthaul transport market switches and depends on the U.S. trade imbalance with the EU. In the case of a U.S. trade deficit with the EU, U.S. imports from the EU are considered the fronthaul market, whereas a trade surplus reverses this definition.
Sources: Containerized Cargo Flow data - *Drewry* and Freight Rate data - *Containerisation International*

early sample periods. The corresponding freight rate differential is relatively small and, in fact, declines over this time period. In contrast, observations from the second quarter of 1997 until the second quarter of 2007 exhibit a clear U.S. trade deficit with the EU, where westbound EU exports to U.S. are clearly defined as the fronthaul transport market. During this period, freight rates adjust to this stark imbalance. As the theory predicts, the freight rate charged to facilitate EU exports to U.S. becomes much larger than the backhaul freight rate charged on U.S. exports to the EU reflecting the reallocation of marginal joint costs towards the fronthaul transport market. At the end of the sample period, however, the U.S. trade deficit reverses into a surplus and U.S. exports to EU become the fronthaul transport

Table 3: Summary Statistics - Control Variables (1995-2009)

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Regional GDP (trillion U.S.$)					
U.S. GDP	57	13.21	1.45	10.41	15.17
Euro-Area (19) GDP	57	11.05	0.91	9.42	12.51
Asia GDP	55	9.70	1.41	7.95	12.31
Regional CPI (2010=100)					
U.S. CPI	57	84.36	9.02	70.40	100.60
Euro-Area (19) CPI	57	86.51	7.42	75.20	98.90
Asia CPI	57	76.92	10.42	59.46	97.40
Crude Oil Prices ($ per barrel)					
WTI - U.S.	57	41.54	26.09	12.94	123.95
Brent - Europe	57	40.00	26.10	11.19	121.40
Dubai - Asia	57	38.00	25.61	10.12	127.59
Containerized Trade Balance					
Imbalance - Trans-Pacific Market	56	0.52	0.14	0.35	0.98
Imbalance - Asia-EU Market	48	0.57	0.097	0.41	0.73
Imbalance - Trans-Atlantic Market	56	0.81	0.11	0.60	1.00

The containerized trade imbalance is defined as the level of backhaul trade relative to fronthaul trade. In the Trans-Pacific market pair, where the U.S. exhibits a trade deficit with Asia over the entire sample period, this would suggest that the trade imbalance captures the ratio of U.S. exports to Asia relative to U.S. imports from Asia.
Sources: GDP & CPI - *OECD*, Crude Oil Prices - *FRED* and Trade Imbalance - *Drewry*

market. Freight rates mirror this change in trade patterns and result in larger transport costs on eastbound U.S. exports to EU relative to U.S. imports from the EU by the end of the sample period. These observations warrant the careful empirical model specification that describes the pricing relations in terms of fronthaul, ij, and backhaul, ji, transport markets, rather than directional east and west bound trade flows that potentially disturb the fronthaul and backhaul distinction.

The remaining data used in the estimation include aggregate income shifters, origin sale prices and shipping cost factors. Table 3 presents the summary statistics on the GDP, CPI, crude oil prices and regional trade imbalances.

5 Results

In this section, we present the empirical results pertaining to the international container shipping industry. The estimates point to the joint determination of trade and transport costs as well as the co-dependence of bilateral transportation markets. Trade exhibits an inelastic long-run response to a persistent change in freight rates, whereas freight rates are found to critically depend on the bilateral trade imbalance. To explore and illustrate the implications of this integration of bilateral transport markets, we conduct several simulation exercises that consider the long-run equilibrium spillover effects arising from various permanent trade and transport shocks. To conclude, we apply the resulting simulation estimates to a counterfactual analysis of the direct and indirect impacts of the Chinese ban on imported waste.

The primary results are based on the group-mean Panel DOLS and FMOLS estimators developed by Pedroni [2001] and Pedroni [2000], respectively. Based on the results of several panel unit root and cointegration tests, presented in Tables 8 and 9 in the Appendix, we find strong evidence in support of the first-order non-stationarity and panel cointegration of our key variables.[33] Given these test results, which suggest the presence of structural relations governing the long-run trade equilibrium in our sample, the time series literature identifies panel cointegration techniques as the preferred method of estimation. In line with the literature and to provide a more complete analysis, we employ and report the results of both of the aforementioned DOLS and FMOLS estimators in Tables 4 and 5, respectively.

[33]The time series econometrics literature has shown that the existence of this cointegration among multiple unit root processes results in super-consistency of traditional equation-by-equation ordinary least squares methods [Hamilton, 1994]. More recent studies, however, by Kao and Chiang [1999] and Pedroni [2000], for example, have since pointed out that endogeneity may take hold in a second-order bias that can significantly influence inference. Several estimators have been proposed by the literature to address this second-order bias and obtain unbiased estimates of the cointegration relation of interest. Among these estimators are various versions of the Fully Modified OLS and Dynamic OLS estimators. Several studies have used Monte Carlo simulations to better understand the small sample properties of these estimators and have drawn comparison across them. Kao and Chiang [1999], for example, show that the 'within-dimension' DOLS estimator outperforms both the OLS as well as the 'within-dimension' FMOLS estimators, and can be applied for both homogeneous and heterogeneous panels. In response to these findings, Pedroni [2000] develops the 'between-dimension' FMOLS estimator employed in this study and demonstrates that it performs well for small samples as well.

Nonetheless, we test the robustness of our findings by estimating the model via traditional fixed-effects and instrumental variables regressions. In general, the traditional estimates, presented in Table 6, point to the robustness of our results. While the fixed-effects estimates are consistent with the presence of the expected endogeneity bias, the instrumental variable approach controlling for this bias provides strong support for the primary results of the integrated fronthaul and backhaul transport costs and resulting bilateral spillover effects.

5.1 *Cointegration Relations Estimation*

Guided by the empirical model and following the cointegration test results, we specify the estimation of the cointegration relations to include panel-specific fixed effects, but exclude market-specific time trends. Generally, we find statistically significant coefficient estimates that provide supporting evidence of our theoretical model. The demand for transport is found to decrease with a rise in transport costs as well as an increase in the domestic sale price. In contrast, aggregate incomes, as expected, exhibit a positive correlation with the demand for transport and international trade. Concerning the determination of long-run equilibrium freight rates, both fronthaul and backhaul pricing relations exhibit an inelastic positive correlation with respect to access costs captured by crude oil prices, but an elastic negative response to increases in origin sale prices. More importantly, both freight rates are found to depend on the bilateral trade imbalance, which indicates the integration of bilateral export and import markets.

Upon closer inspection of the estimated demand relation, reported in column (1) in Tables 4 and 5, we find rather consistent coefficient point estimates across the DOLS and FMOLS estimators. While the coefficient on freight rates turns up insignificant for the DOLS estimator, its magnitude of -0.032 is very similar to the FMOLS estimate of -0.058, which is statistically significant at the 5% level. Focusing on the statistically significant estimate of the FMOLS estimator, the demand cointegration relation suggests that in the long-run a 1% permanent increase in freight rates permanently reduces the volume of con-

Table 4: Cointegration Relations - group-mean panel Dynamic OLS estimator

Variables	**Demand** (1)	**FH Pricing** (2)	**BH Pricing** (3)
Freight Rate (f_{ijt})	-0.032	-	-
	(-0.993)		
Origin Sale Price (p_{it})	-0.485**	-1.723***	-1.530***
	(-2.018)	(-6.407)	(-5.296)
Exporter GDP (y_{it})	0.800***	-	-
	(3.228)		
Importer GDP (y_{jt})	1.238***	-	-
	(5.392)		
Crude Oil Price (op_{ijt})	-	0.287***	0.140**
		(4.770)	(2.415)
Trade Balance (δ_{ijt})	-	-0.229**	0.523***
		(-2.25)	(7.640)
Lags and Leads	1	1 1	
Panels	6	3	3
Observations	320	160	160

Notes: The empirical results were obtained using Pedroni [2001] group-mean panel DOLS estimator. T-statistics are given in parentheses. Statistical significance of coefficients at the 1%, 5%, or 10% level is indicated via ***, **, or *, respectively.

tainerized trade by 0.058%, on average. This very inelastic response of containerized trade (by volume) to a change in real transport costs complements the findings by Egger [2002] and appears reasonable when considering the fact that container freight rates are relatively small compared to the total cargo value of a container.[34] Based on our data sample, a 1% permanent increase in freight rates corresponds to a \$12.5 rise in average transport costs across the primary markets, or a \$15.4 and \$9.7 increase in average fronthaul and backhaul freight rates, respectively. Based on our estimates and the data, this persistent increase in freight rates results in a long-run decrease of average trade by about 2,680 containers per year, or roughly 3,480 and 1,880 containers in fronthaul and backhaul transport markets, respectively. Depending on the composition of the containerized shipments and the respective

[34] Actual estimates of the relative size of freight rates to containerized cargo values range from 0.08% for mid-range clothing to 21.5% for assembled furniture according to Rodrigue et al. [2013].

cargo values, these permanent reductions in the volume of trade are projected to lead to a long-run decline of the average value of trade ranging from \$26.8 million to \$4.8 billion, or \$34.8 million to \$5.6 billion in fronthaul transport markets and \$18.8 million to \$3.0 billion in backhaul transport markets, respectively.[35]

Similar to this finding, the DOLS and FMOLS estimators also show an inelastic long-run response of international trade to a change in the origin sale price. Coefficient estimates range from -0.339 (FMOLS) to -0.485 (DOLS) and are both statistically significant at the 5% level. These findings imply that a persistent 1% increase of domestic goods' prices leads to a 0.34%-0.49% long-run reduction of international containerized exports by the region experiencing the price shock. Both of these inelastic elasticity estimates are very consistent with the theoretical predictions (see Table 1). Depending on the size of the exogenous *ad valorem* trade cost component, τ_{ij}, as well as the trade elasticity of substitution, σ, the theoretically derived elasticities of trade may very well be less than one in absolute magnitude. Furthermore, since prices are expected to exceed shipping costs for most products, we would expect the elasticity of trade to be larger in absolute terms with respect to the sale price relative to transport costs; a finding that is supported by all of our estimates.

Additionally, the results show that long-run increases in economic income measured by the exporter's and importer's GDP drive international trade. This finding is consistent across the DOLS and FMOLS estimators and statistically significant at the 1% level for all four coefficient estimates. Specifically, the DOLS estimates suggest that a permanent 1% increase in exporter GDP raises containerized trade by 0.927% in the long-run, while the same persistent increase in importer GDP raises trade by 1.189% in the long-run. Coefficient estimates of the FMOLS estimator indicate that a persistent 1% rise in exporter GDP leads

[35] The substantial range concerning these effects stems from the considerable variation in container cargo values. According to Rodrigue et al. [2017], the average retail values of a forty foot container can range from \$20,000 to \$3.6 million depending on the traded product. In our data, the volume of trade is measured in twenty, rather than forty foot containers. To account for this difference and obtain a rough estimate of the long-run changes in the value of containerized trade, we divide the upper and lower bound of the indicated container cargo values by two, before multiplying the results by the persistent decline in the volume of shipped containers.

to a permanent 0.632% increase in trade, whereas a permanent 1% increase in importer GDP raises containerized trade by 1.326% in the long-run.

Considering the cointegration relations underlying the supply side of the international transport market in more detail, we have to differentiate between fronthaul and backhaul transport markets. In Tables 4 and 5, the fronthaul and backhaul pricing relations are given by columns (2) and (3), respectively. In general, we find very consistent estimates across both panel cointegration estimators as well as across fronthaul and backhaul transport pricing relations. For example, a 1% permanent increase in the origin sale price is estimated to trigger persistent declines of the fronthaul and backhaul freight rates ranging from 1.517% to 1.723%. All four of these estimates are statistically significant at the 1% level and complement the theoretical predictions. In fact, according to the comparative statics given in Table 1, the negative correlation suggests that the data reflect a rather balanced long-run equilibrium state.

Similar to the impact of origin sale prices, the coefficient estimates on crude oil prices are also consistent across the DOLS and FMOLS estimators and statistically significant at either the 5% or 1% levels. As expected, this relationship is inelastic and positive. A rise in crude oil prices raises container shipping rates. Specifically, we find that a 1% permanent increase in these access costs raises fronthaul freight rates by 0.266%(FMOLS) to 0.287%(DOLS) in the long-run, whereas the same shock leads to a persistent 0.140%(DOLS) to 0.142%(FMOLS) increase in backhaul freight rates.

In order to capture the role that marginal joint costs play in the determination of fronthaul and backhaul transport costs and test whether bilateral spillover effects can arise from this joint-markets structure, the estimation of the fronthaul and backhaul pricing relations includes a measure of the regional trade imbalance. In line with the previously discussed results, the DOLS and FMOLS estimators produce quantitatively and qualitatively similar results for the respective transport markets. Supporting the theoretical predictions, a 1% permanent reduction of the regional trade imbalance triggers a long-run 0.149% (FMOLS)

Table 5: Cointegration Relations - group-mean panel Fully Modified OLS estimator

Variables	**Demand** (1)	**FH Pricing** (2)	**BH Pricing** (3)
Freight Rate (f_{ijt})	-0.058**	-	-
	(-2.450)		
Origin Sale Price (p_{it})	-0.339**	-1.517***	-1.720***
	(-1.995)	(-7.416)	(-9.004)
Exporter GDP (y_{it})	0.599***	-	-
	(3.302)		
Importer GDP (y_{jt})	1.348***	-	-
	(7.325)		
Crude Oil Prices (op_{ijt})	-	0.266***	0.142***
		(6.085)	(3.952)
Trade Balance (δ_{ijt})	-	- 0.149*	0.452***
		(-1.719)	(7.474)
Panels	6	3	3
Observations	320	160	160

Notes: The empirical results were obtained using Pedroni [2000] group-mean panel FMOLS estimator. T-statistics are given in parentheses. Statistical significance of coefficients at the 1%, 5%, or 10% level is indicated via ***, **, or *, respectively.

to 0.229% (DOLS) decline in fronthaul freight rates. In contrast, the same shift towards more balanced trade results in a 0.452% (FMOLS) to 0.523% (DOLS) persistent increase in backhaul freight rates. This closely matches the theorized reallocation of joint costs towards the backhaul market as bilateral trade becomes more balanced. While the backhaul effects are statistically significant at the 1% level, the fronthaul point estimates are statistically significant at the 5% (DOLS) and 10% (FMOLS) levels, respectively.

5.2 *Robustness Analysis*

To test the sensitivity of our findings with respect to the empirical specification, we re-estimate the fronthaul and backhaul pricing relations using fixed effects as well as instrumental variable estimators. Following the time series econometrics literature, the coefficient estimates based on these techniques can potentially suffer from at least one of two impor-

Table 6: Fixed Effects & Instrumental Variables Regressions

	Fronthaul Pricing		**Backhaul Pricing**	
VARIABLES	FE	TSLS	FE	TSLS
	(1)	(2)	(3)	(4)
Origin Sale Price	-1.378***	-1.216***	-1.494**	-1.706***
	(0.189)	(0.153)	(0.257)	(0.265)
Crude Oil Price	0.250***	0.207***	0.188***	0.244***
	(0.041)	(0.042)	(0.053)	(0.054)
Trade Balance	-0.116	-0.196***	0.533***	0.641***
	(0.075)	(0.076)	(0.078)	(0.094)
Observations	160	159	160	159
R-squared	0.378	0.340	0.584	0.555
Durbin score $\chi^2(1)$		3.77*		4.12**
Wu-Hausman F(1,154)		3.74*		4.10**
1st Stage F(2,154)		39.43**		33.88**
Sargan score $\chi^2(1)$		26.99***		1.01

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

tant biases. The first of which can arise due to non-stationarities, or in more technical terms the presence of unit-root processes in the data. Unadjusted for this unpredictable pattern, traditional regression results can be spurious and falsely attribute causation across two truly uncorrelated variables. The second bias concerns the potential endogeneity between international transport costs and the regional trade imbalance due to the presence of reverse causality. Intuitively, a worsening regional trade imbalance caused by a rise in fronthaul trade, for example, triggers an increase in the fronthaul freight rate. This transport cost adjustment, however, has a negative feedback effect that dampens the increase in fronthaul trade. Thereby, the change in the trade imbalance and resulting freight rate adjustment would be lessened and yield a biased coefficient estimate that tends towards zero. While the fixed effects estimator ignores both of these concerns, the instrumental variable approach addresses the issue of endogeneity. Fortunately, the presence of a cointegration relation among multiple unit-root processes results in super-consistency of the traditional equation-by-equation estimator [Hamilton, 1994] and warrants the use of panel cointegration techniques that properly address both of these concerns [Kao and Chiang, 1999, Pedroni, 2000].

The results presented in columns (1) and (3) of Table 6 are based on a fixed-effects regression applied to the unaltered fronthaul and backhaul pricing relations, respectively. Considering the fronthaul transport market, the results are indicative of the aforementioned endogeneity concern biasing the trade balance coefficient towards zero. To address the endogeneity bias, we turn towards an instrumental variable (IV) approach. We instrument for the logged trade balance with the logged ratio of the seasonally adjusted exporter and importer GDP. The results are provided in columns (2) and (4) of Table 6 and include various post estimation test statistics. In general, these tests point to the endogeneity of the trade balance variable and the appropriateness of our instrument across both fronthaul and backhaul transport markets.

Moreover, these results provide robust evidence of our primary findings as well as the theoretical predictions. Using the instrumental variable, we find an economically and statistically significant effect of the trade balance that closely matches the primary estimates for the fronthaul and backhaul transport markets. The remaining, minor differences between any of the panel cointegration and IV point estimates can be explained via the non-stationarities of the time series data overlooked by the instrumental variables approach. Despite these slight discrepancies, all of our findings highlight the presence of the joint production in container shipping industry and illustrates its significance to the determination of international transportation costs incurred to facilitate international trade. Moreover, the dependence of fronthaul and backhaul transport costs on the bilateral trade imbalance suggests that exogenous unilateral exporter(importer) shocks can spillover into the parallel import(export) market. Next, we simulate how such isolated shocks may pass through the entire bilateral system and can lead to traditionally unanticipated consequences.

5.3 Simulation

Taking the simultaneity of trade and transportation costs into account, Table 7 gives the simulated long-term structural responses of bilateral trade and associated transport costs to a variety of persistent supply and demand shocks.[36]

Considering one of the more recent trade policies, we first simulate the traditionally unanticipated spillover effects potentially arising from the Chinese ban on waste imports. Given the current trade data, a complete ban of U.S. waste exports to China would result in a $5.1 billion decline in U.S. exports and worsen the U.S. trade deficit with China by 1.5%. Aside from this primary reduction in U.S. exports, we simulate the long-run spillover effects of this permanent increase in the U.S. trade deficit.

The results, presented in column (1) of Table 7, illustrate that a permanent 1.5% rise in the U.S. trade deficit with China leads to a persistent 0.77% reduction of the backhaul freight rate charged on U.S. exports to China and a 0.34% increase of the fronthaul freight rate charged on U.S. imports from China. The asymmetric and endogenous freight rate adjustment reflects the integration of bilateral transport markets and reallocation of joint costs towards the fronthaul market as regional trade becomes more imbalanced. Naturally, trade responds to these changes in bilateral transport costs. The simulated reduction in the backhaul freight rate leads to a rise in U.S. exports to China that partially offsets the initial $5.1 billion decline. In fact, a back-of-the-envelope calculation suggests that the 0.03% simulated increase in the number of U.S. exported containers raises the value of trans-pacific backhaul trade by $11.7 million to $1.87 billion per year depending on the composition of trade. This, of course, partially offsets the U.S. export loss due to the Chinese ban on waste imports. In contrast to traditional trade theory, our estimates also suggest that the Chinese ban on waste imports leads to a reduction in Chinese exports. This spillover effect into the Chinese export market to the U.S. arises due to integration of bilateral transport costs and the resulting increase in fronthaul freight rates. Calculations based on the simulated

[36]The simulation results are based on the DOLS estimates.

Table 7: Simulation Results

Variables	$\Delta\delta_{ijt}$(-1.5%) (1)	Δoil(10%) (2)	Δp_i (10%) (3)
FH Trade (q_{ij})	-0.011%	-0.092%	-4.267%
BH Trade (q_{ji})	0.025%	-0.046%	-0.073%
FH Freight Rate (f_{ij})	0.335%	2.860%	-18.235%
BH Freight Rate (f_{ji})	-0.766%	1.424%	2.294%

Notes: The simulation results are based on the DOLS cointegration relation coefficient point estimates.

long-run effects, indicate that the anticipated 1.5% rise in the U.S. trade deficit with China leads to a 0.01% fall in the number of exported containers from China to the U.S. valued between $10.6 million to $1.7 billion per year depending on the average containerized cargo value.[37]

In addition to the implications of China's import waste ban, we also consider the effects of changes in regional crude oil and domestic sale prices. In column (2) of Table 7, we simulate the anticipated outcomes of a persistent 10% increase in global crude oil prices. The results reveal that fronthaul freight rates permanently increase by 2.86%, while backhaul freight rates permanently rise by 1.42%. The increases in these unit-specific transport costs coincide with a 0.09% and 0.05% long-run decline in the volume of fronthaul and backhaul containerized trade, respectively. Although the simulated long-run effects on trade are rather inelastic, these simulations, nonetheless, point to the potentially negative externalities of, for example, environmental policy, such as the International Maritime Organization's pollution prevention treaty (MARPOL), aimed at reducing pollution from sea going ships at the expense of carrier fuel costs.[38]

On the demand side of the international transport markets, we explore the impact of a

[37] The sizable range in projected trade effects arises due to the considerable uncertainty concerning container cargo values. As indicated by Rodrigue et al. [2013], cargo values of forty foot containers can vary between $10,000 and $3.6 million depending on the shipped commodity. Given a direct mapping between the composition of U.S.-China containerized trade and the associated values, a more precise estimate would be possible.

[38] Anecdotal as well as empirical evidence suggests that the proposed fuel requirements of this policy may result in a 100% fuel cost premium for container carriers [Notteboom et al., 2010, Ivanov, 2010].

unilateral change in origin sale prices. Considering a 10% permanent increase in country i's sale price, the naive model of trade, ignoring endogenously adjusting freight rates, would predict that a change in country i's sale price only affects country i's exports (see Table 1). Expanding the model to account for the simultaneity between trade and transport suggests that the freight rate charged on country i's exports should also adjust to this change in trade and sale prices, while trade and transport from country j to i remains unaffected. As illustrated in column (3) of Table 7, however, the change in country i's sale prices not only causes an adjustment in country i's exports and the associated transport costs, but also leads to a persistent response of trade and freight rates in the backhaul transport market facilitating trade from country j to country i.

Our simulations suggest that a persistent 10% rise in country i's sale price leads to permanent reduction of fronthaul trade from country i to j by 4.27%, whereas backhaul trade from country j to i also decreases by 0.07%. This feature is explained through the effects of joint production present in the container shipping industry, where carriers adjust both fronthaul and backhaul transport supplies in response to a change in fronthaul demand. The change in relative bilateral trade patterns along with a sizable decrease in the fronthaul demand for transport causes an 18.24% long-run equilibrium decline of the fronthaul freight rate and drives carriers to reallocate marginal joint costs away from the fronthaul and towards the backhaul transport market. Due to the reallocation of marginal joint cost, the impact naturally spills over into the backhaul market. Simultaneous with the fronthaul market adjustments, the 10% rise in country i's sale price triggers a 2.29% persistent increase in the backhaul freight rate and 0.07% permanent decline in backhaul trade, which represents country j's exports to country i.

Overall, this simulation along with the empirical analysis provide strong evidence in support of the theoretical predictions. That is, when accounting for the simultaneity of trade and transport costs as well as the integration of bilateral freight rates, a permanent unilateral shock can spill over across bilateral export and import markets.

6 Conclusion

International trade critically depends on transport markets. The majority of the previous trade models fails to fully capture the unique market-defining characteristics present in the international transportation industry. In our study, we carefully integrate trade and transportation. Furthermore, we develop the transport sector recognizing that the international container shipping markets are subject to the key feature of joint production. Given the model, we evaluate the derived structural relationships by obtaining estimates of the cointegration relations present in the data. The results we obtain show the existence of long-run equilibrium relations that govern the simultaneous determination of trade and transport costs as well as the integration of these bilateral freight rates.

This integration is shown to be a key instrument in explaining potential spillover effects across bilateral import and export markets. We use our estimates to simulate the potential spillover effects arising the recent Chinese ban on imported waste. We find that this $5.1 billion ban on U.S. exports and the associated 1.5% increase in the U.S. trade deficit with China could lead to not only a 0.77% reduction in transport costs on U.S. exports, but also a 0.34% increase on freight rates charged on U.S. imports from China. Trade is shown to respond accordingly, predicting that the import ban will not only reduce Chinese imports from the U.S., but also the bilaterally-integrated Chinese exports to the United States.

Based on the findings in this study, there are several research questions that are of potential interest. Future studies might examine the nature of the long-run equilibrium relations between trade and trade cost established in this study at a more disaggregated level. Of particular interest could be whether these relations differ between countries with varying trade compositions and levels of development. Of course, any such study hinges on the development of disaggregated data that reflect trade flows and trade costs at the product and/or country level. Alternatively, an interesting avenue for future research is to focus on the varying response between front- and backhaul trade given various trade cost reducing policy measures. Further inquiry should delineate between the policy impacts on exports and imports facilitated in fronthaul and backhaul transport markets and deduce policy implications stemming from these varying responses.

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7 Appendix

To establish the time series properties of our data, we first apply multiple panel unit root tests to all of the individual time series used in the estimation. Several of these tests point to non-stationarities and integration of order one. Given the non-stationarity of several time series, we proceed with tests for panel cointegration developed by Pedroni et al. [1999] and Pedroni [2004]. These tests produce supporting evidence of the existence of the panel cointegration underlying the empirical model specification.

7.1 *Unit root tests*

The results of the panel unit root tests are given in Table 8 and are presented for the levels as well as first differences of each time series. The tests included in the analysis are the Levin-Lin-Chu (LLC) test [Levin et al., 2002], as well as Phillips-Perron (PP) and augmented Dickey-Fuller (ADF) tests developed by Choi [2001].[39,40] While the adjusted t-statistic is reported for the LLC test, the Z-statistic, as recommended by Choi [2001], is reported for the ADF and PP tests. After careful graphical examination of each level time series, a time trend has been included in the regression equations of the tests for the transport quantity demanded, exporter/importer GDP, CPI, and crude oil prices. Considering the panel unit root tests on the differenced data no time trends were included in the regression equations. While none of the time series were demeaned prior to any of the tests[41], the issue of lag selection has been addressed with the Hannan-Quinn Information Criterion (HQIC).

As the test-statistics reported in Table 8 suggest, we have strong evidence that at least

[39] These tests are, of course, based on the work by Phillips and Perron [1988] as well as Dickey and Fuller [1979] and Dickey and Said [1981], respectively.

[40] While there are a number of other tests available, the specific tests chosen for this analysis are built on assumptions that best fit the data employed in this study. Some of these assumptions, include the fact that they are designed for a finite number of cross-sections and allow for the possible inclusion of cross-section specific fixed effects and time trends. Other commonalities include the fact that all three tests maintain the null hypothesis that the time series exhibits a panel unit root. The chosen tests, however, differ in their respective alternative hypotheses. For a finite number of cross-sections the alternative hypothesis of the PP and ADF tests holds that the time series of at least one cross-section does not exhibit a unit root. In contrast, the LLC test operates under the alternative hypothesis that none of the cross-sections exhibit a unit root.

[41] Demeaning panel data is used to control for cross-sectional dependencies. However, exporter/importer GDPs are identical across some of the three market pairs. For example, the U.S. is an exporter to Asia in the Trans-Pacific market as well as Europe in the Trans-Atlantic market. This creates cross-sectional dependencies concerning exporter and importer GDP. Thus, exact cross-sectional dependencies for these time series is an artifact of the bilateral nature of trade, and demeaning these data distorts important variation. The empirical results of the panel unit root tests are generally robust to demeaning the remaining time series and are available upon request.

Table 8: Panel Unit Root Tests

Variables	Levels LLC	Levels Fisher -DF	Levels Fisher -PP	1st Difference LLC	1st Difference Fisher -DF	1st Difference Fisher -PP
Demand						
Quantity (q_{ijt})	-2.68***	2.00	2.11	-13.76***	-5.78***	-14.23***
Freight Rate (f_{ijt})	-2.46***	-3.58***	-1.18	-6.92***	-7.89***	-8.60***
Origin Sale Price (p_{it})	-0.54	-1.84**	0.34	-7.23***	-6.51***	-10.31***
Exp/Imp GDP (y_{it}/y_{jt})	1.54	0.85	4.07	-5.74***	-4.09***	-7.19***
FH Pricing Relations						
Freight Rate (f_{ijt})	-3.54***	-2.59***	-0.89	-6.98***	-5.16***	-7.75***
FH Origin Sale Price (p_{it})	-0.20	-0.99	-3.07***	-11.68***	-5.73***	-8.77***
FH Crude Oil Price (op_{ijt})	-4.12***	-2.83***	-1.45*	-4.48***	-5.11***	-7.93***
Trade Balance (δ_{ijt})	0.28	0.32	0.18	-9.88***	-5.87***	-10.53***
BH Pricing Relations						
BH Freight Rate (f_{jit})	-1.32*	-2.37***	-1.47*	-8.46***	-6.42***	-7.95***
BH Origin Sale Price (p_{jt})	-0.77	-1.34*	0.34	-13.67***	-4.90***	-9.94***
BH Crude Oil Price (op_{jit})	-3.75***	-3.42***	-1.30*	-6.15***	-5.10***	-6.68***
Trade Balance (δ_{ijt})	0.28	0.32	0.18	-9.88***	-5.87***	-10.53***

Notes: Reported are the adjusted t-statistics obtained from the LLC test and the Z-statistics for both of the Fisher-type tests as suggested by Choi (2001). Rejection of the null of a panel unit root at the 1% (5%, 10%) significance level is indicated with *** (**, *).

two of the time series in the demand and each of the pricing relations are integrated of order one. On the demand side, the majority of the tests show that we cannot reject the null hypothesis of a panel unit root for the level of trade and thus, the transport quantity demanded, origin sale price and exporter/importer GDP. In contrast, the test results on freight rates are mixed. Although the PP test fails to reject the null hypothesis of a panel unit root at the 1% significance level, the LLC and ADF test reject the existence of a panel unit root at the 1% level. Identical tests applied to the first difference of the non-stationary variables strongly reject the null hypothesis of a panel unit root suggesting that the transport quantity demanded, origin sale price and exporter/importer GDP are, in fact, integrated of order one, while freight rates may be integrated of order one.

Concerning the pricing relations, the majority of the tests provide strong evidence that fronthaul and backhaul origin sale prices as well as the trade imbalance reflect a panel unit root. Evidence of a panel unit root concerning freight rates, however, is rather mixed. That is, for the fronthaul freight rate the Fisher-type PP test fails to reject the null hypothesis of a panel unit root at any significance level, while both the LLC and Fisher-type ADF test reject the null at the 1% level. Similarly, for the backhaul freight rate, both the LLC and Fisher-type PP tests fail to reject the null hypothesis of the presence of a panel unit root at the 5% significance level, whereas the Fisher-type ADF test rejects the null at the 1% level. Tests on fronthaul and backhaul crude oil prices exhibit a very similar pattern. Only the Fisher-type PP test fails to reject the null of panel unit root at the 5% level. Contrary to these mixed findings all of the tests suggest that the first difference of all variables is stationary at the 1% significance level. Based on these tests results, we conclude that fronthaul and backhaul origin sale prices and the trade imbalance are also integrated of order one, while fronthaul and backhaul freight rates and crude oil prices may be integrated of order one.

Given the fact that all variables are integrated of order one or less and that at least two variables of the demand and each pricing relation are integrated of order one, the empirical analysis continues with the panel cointegration tests developed by Pedroni et al. [1999] and Pedroni [2004].[42]

7.2 *Cointegration Tests*

To allow for the heterogeneity across transport markets, the panel cointegration tests are based on Pedroni's (1999, 2004) seven test-statistics and critical values. Due to varying small sample properties, we report all test statistics. Consistent with the panel unit root tests, we do not demean any of the time series embedded in the empirical model. However, we do allow for cross-section specific fixed effects and use the tests to determine the potential inclusion of time trends present in the cointegration relations.

[42] As Pesaran et al. [2001] point out the existence of *level relationships* is not dependent on all variables being integrated of order one.

The results of these tests are presented in Table 9 and provide supporting evidence of the existence of cointegration relations between trade, transport costs, sale prices and aggregate income on the demand side and bilateral transport costs, the trade imbalance, sale prices and shipping cost factors on the supply side. Concerning the demand for international containerized shipments, four out of the seven tests excluding a time trend reject the null hypothesis of no panel cointegration at the 5% level, while the Group pp-test rejects the null at the 10% level. This rejection rate declines drastically once a time trend is included. We interpret these findings as strong evidence for the existence of a trend exclusive cointegration relation that governs international trade, and thus, the demand for transport, as a function of transport costs, the domestic sale price and exporter as well as importer aggregate incomes.

Concerning the pricing relations governing international containerized shipments, we test for the existence of cointegration differentiating between fronthaul and backhaul transport markets. While the cointegration tests excluding a time trend provide only limited evidence of a cointegration relation concerning the fronthaul pricing relation (two of the tests reject the null of no cointegration at the 10% or 5% level), the existence of a time trend exclusive cointegration relation governing the backhaul pricing relation is strongly supported by five out of seven tests at either the 5% or 10% significance level. In contrast, the existence of time trend inclusive cointegration relations is soundly rejected for both pricing relations and thus, estimations are carried out without a time trend.

Although the evidence is relatively weaker for the fronthaul pricing relation, we interpret these results as overall supporting evidence for the existence of cointegration relations that describe the long-run equilibrium relationships suggested by the theoretical model of trade and transportation.

Table 9: Panel Cointegration Tests

Statistics	Demand (1)	Demand (2)	FH Pricing (3)	FH Pricing (4)	BH Pricing (5)	BH Pricing (6)
Panel ν-statistic	2.00**	1.20	1.49*	0.40	2.31**	1.81**
Panel ρ-statistic	-1.13	-0.62	-0.36	0.46	-1.21	-0.31
Panel pp-statistic	-1.80**	-1.55*	-0.54	0.20	-1.48*	-0.78
Panel adf-statistic	-1.86**	-2.15**	-1.22	-0.36	-1.54*	-0.44
Group ρ-statistic	-0.37	0.32	0.23	0.94	-0.59	0.11
Group pp-statistic	-1.54*	-1.54*	-0.29	-0.45	-1.33*	-0.59
Group adf-statistic	-2.03**	-2.19**	-1.99**	-1.06	-1.60*	-0.30
Trend	no	yes	no	yes	no	yes

Notes: All statistics are normalized to be distributed N(0,1). For the ν-statistic only the right tail of the normal distribution is considered, while for all others only the left tail of the normal distribution is considered as the rejection region for the null hypothesis of no cointegration. *** (**,*) indicates rejection of the null hypothesis at the 1% (5%, 10%) significance level.