Trade, Transportation and Trade Imbalances: 
An Empirical Examination of International Markets and Backhauls*

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Abstract
In this paper, we develop and estimate a model of international trade and transportation. The model consists of two regions that trade with one another creating potential demands for transport in each direction. Supply of transport to both markets is provided under conditions of joint production. In equilibrium, unit-specific trade costs in the form of freight rates adjust to differences in international demands for transport and can result in balanced or imbalanced equilibrium trade in the presence of asymmetric freight rates. Empirically, we use data from three different sets of markets that comprise the bulk of world trade. Empirical tests show the existence of cointegration relations between trade, unit-specific trade costs, trade prices and aggregate income and we estimate the structural model using panel cointegration techniques. The results exhibit the simultaneity of international trade and transportation costs and point to relatively inelastic long-run equilibrium demand and pricing relations in the international container shipping industry. The estimates show that a 1% permanent increase of freight rates leads to a 0.06% long-run equilibrium decline in volume of containerized international trade, while the effects of a change in the trade imbalance vary across transport markets. We estimate that a persistent 1% increase in the trade imbalance leads a 0.35% long-run equilibrium rise and a 0.45% permanent decline of freight rates charged in net exporting fronthaul and net importing backhaul transport markets, respectively.

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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 the
costs of transportation between countries has, along with rising incomes, fueled the growth of
international trade and the interest in developing models that link trade and transportation
together.

A plethora of models of international trade, based on variety of underlying assumptions,
and multitude of empirical studies have pointed to the fact that trade costs are one of the
key determinants of international trade. Studies that are directly focused on these barriers
to trade, e.g. Hummels [2001], Anderson and van Wincoop [2004] or Hummels [2007], have
established that transportation costs are a principal element of these trade costs. In fact,
Anderson and van Wincoop [2004] find that transportation costs account for 21% of total
trade costs. Yet, despite its importance to the determination of these costs and international
trade, transportation has played only a secondary role in the trade literature, historically.
In recognition of this gap in the literature, studies by Behrens et al. [2006], Hummels et al.
[2009], Luo [2011] and Kleinert and Spies [2011] and our study, for example, integrate a
transport sector into various models of trade.

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1A recent study by Bernhofen et al. [2016] finds that the reduction in transport costs due to container-
ization 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%.

2Some of these underlying foundations include absolute cost advantages [Smith, 1776], Ricardian com-
parative cost advantages [Dornbusch et al., 1977, Eaton and Kortum, 2002, Bernard et al., 2003], varying
factor endowments [Heckscher and Ohlin, 1991], differences in incomes and trade costs [Samuelson, 1952],
economies of scale and a taste for variety [Krugman, 1979], and heterogeneous productive efficiencies [Melitz,
2003], among others.

3See, 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 the present study, we expand upon this recent literature and derive a model of transportation demand based on trade determinants, to which we 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. These features introduce the key dynamics and have significant implications for the equilibrium determination of freight rates and trade patterns and separate our theoretical model of a transport sector from the majority of the previous work in the trade literature.

Trade between countries is typically not balanced with the result that the joint transportation supplies into and out of a country are not equal. In the transportation economics literature, this is referred to as the backhaul problem.\(^4\) There are a number of studies that examine the backhaul problem and its effect on decisions to serve transport markets [Wilson and Beilock, 1994, Wilson, 1994], as well as the determination of prices in these markets [Nicholson, 1958, Basemann and Daugherty, 1977, Wilson, 1987, Demirel et al., 2010]. In the presence of the backhaul problem, freight rates charged in the fronthaul and backhaul transport markets\(^5\) facilitating imbalanced trade between two trading regions exhibit large differentials.\(^6\) Studies by Takahashi [2011], Behrens and Picard [2011], and Jonkeren et al. [2011] have examined the effects of these freight rate differentials on the distribution of economic activity and pointed to the trade imbalances as an explanation for them. A central unanswered question of interest concerns the quantitative long-run impact of freight rates and their differentials on the demand for cargo transportation and thus, international trade.

\(^4\)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 \(ij\).

\(^5\)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.

\(^6\)Fan et al. [2014] present a nonstructural time series analysis of the freight rate differentials and the cointegration of the joint prices of fronthaul and backhaul which vary with the trade imbalance.
Our research sheds light on this question by developing and estimating a model that combines the literatures on both trade and transportation. Specifically, the trade framework follows Hummels et al. [2009], while the transportation sector is derived from research on the backhaul problem done by Wilson [1987], Wilson [1994] and Wilson and Beilock [1994]. We extend the model discussed by Hummels et al. [2009] by incorporating an international transport sector that accounts for the possibility of the backhaul problem faced by international carriers operating on bidirectional markets and use this structural model to gain insights into the long-run dynamics of this industry as well as the backhaul problem. Our model predicts that when the demands for internationally traded goods are imbalanced, balanced bilateral trade can only arise in the presence of endogenously adjusting asymmetric unit-specific trade costs. That is, balanced bilateral in conjunction with the traditional assumption of symmetric trade costs can only arise between identical countries. Furthermore, we show that this asymmetric endogenous adjustment of trade costs can lead to biased coefficient estimates and accounts for unanticipated spillover effects of an idiosyncratic shock to joint transport markets facilitating bilateral trade.

We apply the model to data on three different sets of transport markets facilitating trade by container between Asia and the US, Asia and Europe, and the US and Europe. The empirical tests employed in this study exhibit strong long-run relationships between trade and transportation that reflect the static equilibrium relations derived from the theory. The results point to the importance of freight rates in the determination of the demand for transport and thus, the importance of unit-specific trade costs in the determination of trade. Specifically, we show that there are cointegration relations that establish the simultaneity between trade and transport costs and govern the long-run equilibrium supply and demand conditions of the international transport markets facilitating international trade. The estimated cointegration equations provide long-run structural relationships that support the general findings of static cross-sectional analyses in the trade literature. That is, trade between two trading regions is driven by aggregate income measures and reduced by trade
costs. In particular, we show that the estimated long-run equilibrium trade relation supports the general finding of unit elasticity of trade with respect to exporter and importer aggregate income [see, for example, Bergstrand, 1985, Baier and Bergstrand, 2001, Egger, 2002, Carrere, 2006]. Our point estimates range from 0.927 to 1.189 and are shown not to be statistically different from one at any conventional significance level.

In addition, we find that in the long-run a 1% permanent increase of freight rates leads to a 0.058% permanent decline of trade, while fronthaul and backhaul freight rates show varying long-run responses to changes in the trade imbalance between two trading countries. Our estimate of this relatively inelastic long-run response of trade to an increase in unit-specific trade costs is in line with the literature\(^7\) and appears reasonable given the fact that container freight rates represent only a small fraction of the value of the goods shipped.\(^8\) In fact, given our data, this estimate implies that a persistent increase of the average freight rate by $12.5 leads to a long-run reduction of the volume of containerized trade by about 670,000 twenty-foot containers, on average. Based on the variation in container cargo retail values 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 $6.7 billion to $1.2 trillion.

The specific point estimates accentuate the importance of transportation in the determination of trade and highlight port and maritime transit policy measures as a key instrument to stimulate the growth of international trade. In fact, the empirical results lend themselves for the evaluation of potential transport cost reducing policy measures and their long-run impact on trade. Simulations based on the coefficient estimates suggest, for example, that a persistent 10% increase in market shipping capacity is anticipated to permanently lower

\(^7\)Egger [2002] compares gravity results 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.

\(^8\)According to the Rodrigue et al. [2013] the average value of a forty foot container ranges between $20,000 and $3,600,000 depending on the type of cargo. In contrast, our data show that average freight rates for a twenty foot container range from $835 to $1717 depending on the market.
unit-specific trade costs in the form of container freight rates by 7.284% in fronthaul transport markets and 4.290% in backhaul transport markets. Based on our simulations, these long-run equilibrium reductions of freight rates coincide with a 0.321% permanent increase in the volume of fronthaul trade and a 0.189% permanent increase in volume of backhaul trade. Overall, the primary contributions of our study are twofold. First, we develop a model that integrates trade and transportation with an explicit representation of the joint production present in the liner shipping industry. 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.

The remainder of this paper is organized as follows: In section 2, we present a theoretical model of transportation markets. The empirical model is developed in section 3. Section 4 summarizes the data employed. These data exhibit dramatic differences across markets in terms of the level of trade imbalances and freight rate differentials. Section 5 contains the empirical results which are generated from panel time series techniques. Indeed, the examination points to most of the variables having unit roots and the existence of long-run cointegration relations between trade and transportation. 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 depends on the trade imbalance. 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, $j=1,2,\ldots,M$, 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]. The price elasticity of demand, $\sigma$, 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

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

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 $q_{ij}$.

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 sales price of a variety from country $i$ is represented by $p_i$ and taken as given by carriers. Given the fact that each representative consumer has a taste for variety\(^9\) and goods are differentiated by origin, there is an incentive

\(^9\)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.
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 sales price, $p_i$. That is, $p_{ij} = p_i \tau_{ij} + f_{ij}$, where the transport and *ad valorem* trade costs are taken as given by each representative consumer.\(^\text{10}\)

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:

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

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. However, it is important to make note 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 $j$. This trade imbalance particularly holds for containerized cargo flows which implies that demands for transportation in the market pair $ij$ are imbalanced.\(^\text{11}\)

Following common terminology the transport market served on a round trip facing higher

\(^{10}\)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].

\(^{11}\)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.
demand is denoted as the *fronthaul*, while its counterpart, the transport market facing lower demand, is denoted as the *backhaul*.\(^{12}\)

### 2.2 Supply of Transport

In this study, 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 between country \(i\) to country \(j\), 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\(^{13}\) and forces carriers to adjust transport supplies accordingly. In equilibrium, this results in transportation costs that adjust to the existing demand imbalance.\(^{14}\) 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 \(l = 1, \ldots, N\) symmetric carriers.

\(^{12}\)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.

\(^{13}\)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.

\(^{14}\)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 2(b), 2(d), and 2(f) 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 straightforward.
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 \( q_{ji} \), between countries \( i \) and \( j \) 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. Therefore, each carrier’s round trip costs can be expressed as follows:

\[
C^l = a_{ij}Q_{ij}^l + a_{ji}Q_{ji}^l + JC(K^l) \quad \forall l = 1, \ldots, N \text{ and } i, j = 1, \ldots, M, \ i \neq j.
\] (3)

Given this cost structure, each carrier chooses the profit maximizing transport capacity, \( K^l \), and optimal supplies of transport, \( Q_{ij}^l \) and \( Q_{ji}^l \), that are offered to each market on a given round trip.\(^{15}\) Each carrier’s profit from a given round trip between country \( i \) and country \( j \) can be written as

\[
\max_{K^l, Q_{ij}^l, Q_{ji}^l} \Pi^l = f_{ij}Q_{ij}^l + f_{ji}Q_{ji}^l - C^l \quad \forall l = 1, \ldots, N \text{ and } i, j = 1, \ldots, M, \ i \neq j
\] (4)

subject to \( K^l \geq Q_{ij}^l, \ K^l \geq Q_{ji}^l \)

Solving each carrier’s constrained profit maximization problem results in three \( N \times 1 \) vectors of first-order conditions, along with the standard Kuhn-Tucker conditions, that can be

\(^{15}\) 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.
The first order conditions with respect to transport supplies, given by equations (5a) and (5b), can be seen as each carrier’s market access conditions indicating that marginal revenues in either transport market must cover access costs for a given market to be served. In addition to that, each carrier’s first order condition with respect to allocated capacity can be interpreted as the service condition. That is, given the fact that the Kuhn-Tucker multipliers, $\lambda_1$ and $\lambda_2$, 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:

$$q_{ij} = \sum_{l=1}^{N} Q^l_{ij} \quad (6a)$$

$$q_{ji} = \sum_{l=1}^{N} Q^l_{ji} \quad (6b)$$

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, \( K^l \geq Q^l_{ij} \) and/or \( K^l \geq Q^l_{ji} \), 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 equilibria derived from our model.

Second, the set of potential equilibrium cases includes solutions where optimal transport supplies and international trade are zero valued 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 case. 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 sales prices as well as the endogenously adjusting freight rate differential. Intuitively, small differences in the bilateral demands for transport, due to small sales 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 sales 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 sales price variation and leads to imbalanced bilateral trade. In fact, it can be shown that a balanced trade equilibrium only arises when \( p_{j} \tau_{ji} - p_{i} \tau_{ij} \in \left( a_{ij} - a_{ji} - \frac{\partial J C(K_{l}^{j})}{\partial K_{l}}, a_{ij} - a_{ji} + \frac{\partial J C(K_{l}^{j})}{\partial K_{l}} \right) \), whereas an imbalanced trade equilibrium, where exports from country \( i \) to country \( j \) exceed exports from country \( j \) to country \( i \), results when \( p_{j} \tau_{ji} - p_{i} \tau_{ij} > \left( a_{ij} - a_{ji} + \frac{\partial J C(K_{l}^{j})}{\partial K_{l}} \right) \).\(^{16}\) Both of these scenarios can be represented graphically and are depicted by Figures 1(a) and 1(b).

Figure 1(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 1(a) shows, the size of the potential freight rate differential depends on the actual imbalance of the demands for transport. Furthermore, Figure 1(a) illustrates that this differential between freight rates mitigates the difference in sales prices (inclusive of *ad valorem*

\(^{16}\)Due to symmetry, trade is also imbalanced when \( p_{i} \tau_{ij} - p_{j} \tau_{ji} \geq \left( a_{ij} - a_{ji} + \frac{\partial J C(K_{l}^{j})}{\partial K_{l}} \right) \). In this case, country \( j \) becomes the net exporter and the transport market \( ji \) becomes the fronthaul.
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 sales prices to vary across countries, Figure 1(a) shows that this 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 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 1(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 sales price variation across countries, each carrier optimizes by choosing asymmetric transport supplies, $Q_{ij}^l \neq Q_{ji}^l$. 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 between country \( i \) and \( j \) and the resulting equilibrium transportation rates can be derived as follows\(^{17}\):

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

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

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

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 between country \( i \) and \( j \), where transport market \( ij \) is considered the fronthaul:

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

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

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

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

\(^{17}\)Note that the derivation of the optimal supplies of transport and resulting equilibrium freight rates relies on the symmetry of carriers.
Thus, in the balanced trade case, the partial equilibrium, \((q_{ij}, q_{ji}, K_{ij}, Q_{ij}, Q_{ji}, f_{ij}, f_{ji})\), of the transport market pair \(ij\) facilitating balanced bilateral trade between countries \(i\) and \(j\) is described by equations (2) and (8a)-(8c). Whereas, in the imbalanced trade case, the partial equilibrium, \((q_{ij}, q_{ji}, K_{ij}, Q_{ij}, Q_{ji}, f_{ij}, f_{ji})\), of the transport market pair \(ij\) facilitating imbalanced bilateral trade between countries \(i\) and \(j\) 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 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.

### 2.4 Comparative Statics

One of the key results obtained from various estimations of the gravity equation is the dependence of trade on aggregate income and trade costs. As Head and Mayer [2013] point out, standard trade estimations use proxies, such as distance and cultural as well as geographical ties between trading countries to capture trade costs. However, these trade cost proxies have limitations. For example, Limao and Venables [2001] point out that distance
is only weakly related to transport costs, while Combes and Lafourcade [2005] show that it fails to correlate with time-varying transport costs. Thus, in the absence of a unit-specific trade cost proxy or in cases where common controls do not correlate with transportation rates, failure to model the endogeneity of international shipping costs may result in biased coefficient estimates. The existence of such a potential bias can be shown with the theoretical model above. As equations (8a)-(8c) as well as (9a)-(9d) illustrate, the determination of equilibrium transportation rates partly depends on the determinants of international trade, namely the domestic sales prices. Therefore, unit-specific trade costs captured by international shipping rates cannot be held constant given a change in these sales prices. Instead, the simultaneous change in trade costs leads to a secondary impact on trade that alters the initial response.

Consider, for example, an exogenous shock to country $i$’s domestic sales price, $p_i$.\(^{18}\) Given equation (2), the partial derivative that captures the overall response of trade from country $i$ to country $j$ to a shock in country $i$’s sales price is given by:

$$
\frac{\partial q_{ij}}{\partial p_i} = -\sigma \left[ \frac{\sigma}{\sigma - 1} (p_i \tau_{ij} + f_{ij}) \right]^{-\sigma-1} \frac{\sigma}{\sigma - 1} \left[ \tau_{ij} + \frac{\partial f_{ij}}{\partial p_i} \right]
$$

(10)

If freight rates are assumed to be exogenous to the system, it must be true that $\frac{\partial f_{ij}}{\partial p_i} = 0$. However, if we consider equations (8b) and (8c) as well as (9c), it becomes clear that equilibrium freight rates depend on the domestic sales price, regardless of the trade imbalance. To derive the specific response of freight rates, we have to differentiate between the balanced and imbalanced trade scenarios.\(^ {19}\) In the imbalanced trade case, the responses of the fronthaul and backhaul equilibrium freight rates to a shock in country $i$’s sales price are given by:

\(^{18}\)The general interpretation of the following theoretical findings would hold if country $j$ experienced a price shock instead.

\(^{19}\)We abstract from knives’ edge cases where a change in sales prices causes a switch in the equilibrium from balanced to imbalanced trade or vice versa.
\[
\frac{\partial f_{ij}}{\partial p_i} = \frac{1}{\sigma N - 1} \tau_{ij} > 0 \text{ (fronthaul)} \quad (11a)
\]
\[
\frac{\partial f_{ji}}{\partial p_i} = 0 \text{ (backhaul).} \quad (11b)
\]

In contrast, in the balanced trade case an identical shock leads to the following responses of the fronthaul and backhaul equilibrium freight rates:

\[
\frac{\partial f_{ij}}{\partial p_i} = \frac{2 - \sigma N}{2 \sigma N - 2} \tau_{ij} \text{ (fronthaul)} \quad (12a)
\]
\[
\frac{\partial f_{ji}}{\partial p_i} = \frac{\sigma N}{\sigma N - 1} \tau_{ij} > 0 \text{ (backhaul).} \quad (12b)
\]

These derivatives highlight several important findings. First, regardless of whether a balanced or imbalanced trade equilibrium is considered, equations (11a) and (12a) show that fronthaul freight rates adjust to an increase in the net exporter’s sales price. However, the size and direction of the potential bias varies between the balanced and imbalanced trade cases. If \( N > 2 \), the fronthaul freight rate, in the balanced trade case, decreases in response to the price shock, while the fronthaul freight rate increases in the imbalanced trade case. Intuitively, while an increase in the sales price causes the demand for transport to fall in both cases, carriers exercising market power adjust the fronthaul transport supply differently across the two scenarios. In the imbalanced trade case, carriers are unconstrained concerning their adjustment of transport supply viewing fronthaul and backhaul as separate products. In contrast, in the balanced trade case, carriers are constrained to keep transport supplies symmetric across fronthaul and backhaul markets leading to a smaller supply adjustment. Overall, this derivation shows that as long as carriers hold market power, the common estimate of \( \frac{\partial q_{ij}}{\partial p_i} \) clearly depends on the endogenous adjustment of unit-specific trade costs in response to a change in the determinants of trade and may bias traditional gravity estimations.
Second, equations (11b) and (12b) demonstrate that the backhaul freight rate remains unchanged in the imbalanced trade case, whereas the backhaul freight rate, in the balanced trade case, increases in response to a change in country $i$’s sales price. This result stems from the presence of joint production in the transportation industry. When trade is balanced, fronthaul and backhaul supply are joint products which leads to the integration of fronthaul and backhaul freight rates. Factors that drive a change in the fronthaul market will trigger a response in the backhaul transport market as well. Specifically, since the fronthaul transport supply decreased in the balanced trade case, a shock to the net exporter’s domestic sales price must also cause a reduction in the backhaul transport supply, so that trade remains balanced. This reduction in the backhaul transport supply, naturally leads to the increase in the backhaul freight rate given by (12b). Since the elasticity of trade with respect to transport costs is negative, this, of course, results in a reduction of trade facilitated in the backhaul market. Therefore, our model, built on a standard trade framework and accounting for the presence of joint production in the international transportation industry, predicts that when trade is balanced, a trade shock pertinent to country $i$’s exports also leads to an adjustments of country $i$’s imports. This result compliments the finding by Deardorff [2014] who shows that the presence of unit-specific trade costs can distort traditional trade theory results.

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. In particular, for any of the given transport market pairs, the estimation is focused on the demand for transport and fronthaul and backhaul pricing relations described by the static partial equilibrium framework. Since the data are quarterly time series observations in three market pairs and our goal is to uncover the static long-run equilibrium relations implied by the structural
model, the empirical specifications allow for the use of time series techniques to estimate the static long-run system of equations. In particular, we employ panel cointegration methods to estimate 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, the demand equation is considered. As equation (2) indicates, the demands for transportation in market pair $ij$ are given by the quantity of containerized bilateral trade facilitated between region $i$ and region $j$ and are a function of sales prices, ad valorem and unit-specific trade 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 between any two regions $i$ and $j$ 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 sales price is denoted $p_{it}$, whereas unit-specific trade costs are given by the container freight rate, $f_{ijt}$, that is charged to facilitate trade from region $i$ to region $j$. Although the theoretical model, due to its partial equilibrium nature, does not indicate aggregate income to be a determinant of international trade, we follow the vast majority of the trade literature that suggests that aggregate income plays a central role in the determination of trade and thus, the international demand for transport. Following standard practice, aggregate income is given by exporter and importer real GDP and denoted by $y_{it}$ and $y_{jt}$, respectively.

To capture the unobservable characteristics and control for the heterogeneity between trade routes, a transport market specific fixed effect, $\alpha_{ij}$, 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. 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, we do not integrate a market pair specific time trend in the empirical model of the demand for transport.

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 $\Delta x_{ijt}$, control for the endogenous feedback effect that is present between international trade and unit-specific trade costs as well as the other determinants of trade. Consequently, the theoretically motivated empirical specification of the demand for transport becomes

$$q_{ijt} = \alpha_{ij} + \beta_1 f_{ijt} + \beta_2 p_{it} + \beta_3 y_{it} + \beta_4 y_{jt} + \sum_{s=-S}^{S} \Theta \Delta x_{ijt+s} + \epsilon_{ijt},$$  \hspace{1cm} (13)

where all variables are in logged form, $S$ indicates the maximum number of lags and leads included in the model and the error term is denoted by $\epsilon_{ijt}$. The cointegration relation and coefficients of interest are described by $\beta_1$-$\beta_4$. Accurately estimating the cointegration relation underlying the demand equation renders the residual stationary and implies that any variation from this long-run static equilibrium relationship is only temporary.\(^{21}\)

\(^{20}\)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 included in the empirical model. However, to the extent that *ad valorem* trade costs differ across supranational geographic regions, time-invariant *ad valorem* trade costs are captured by the market pair specific fixed effects.

\(^{21}\)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...
To complete the empirical model and demonstrate the simultaneity between trade and transportation as well as test for the presence of joint production concerning the facilitation of international containerized trade, 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 $f_{jit}$. These unit-specific trade costs are each modeled as a function of the respective number of carriers, as well as access and marginal joint costs. The number of carriers competing in market pair $ij$ is captured via this market pair’s cumulative shipping capacity, $sc_{ijt}$. Access costs are controlled for via bunker fuel prices, denoted by $bf_{ijt}$. While it is expected that an increase in the price of bunker fuel raises access cost and thus, increases the equilibrium freight rates, an increase in market shipping capacity is associated with intensified competition that diminishes market power and is, thus, expected to lead to a reduction of international freight rates.

Lastly, we specify a proxy for marginal joint costs. 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 equilibria. To capture this switching dependence of the backhaul freight rate and control for marginal joint costs, the relative trade imbalance, $\delta_{ijt}$, is integrated in the fronthaul and backhaul empirical pricing relations. Careful consideration of the theoretical model suggests that an increase of the trade imbalance is associated with an increased allocation of marginal joint costs towards the fronthaul transport market. That is, fronthaul freight rates are expected to increase, given a rise of the trade imbalance. In contrast, this reallocation of marginal joint costs away from the backhaul transport market, caused by an increase in the 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.

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trade imbalance, is associated with a reduction in the backhaul freight rate which no longer covers the reallocated portion.

Again, we incorporate market pair specific fixed effects 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 $\Delta z_{ijt}$, 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 \((8c)\) as well as \((9c)\) and \((9d)\), this leads to the following empirical pricing relation specifications;

\[
\begin{align*}
    f_{ijt} &= \alpha_{ij} + \gamma_{ij}^{1} sc_{ijt} + \gamma_{ij}^{2} bfp_{ijt} + \gamma_{ij}^{3} \delta_{ijt} + \sum_{s=-S}^{S} \Phi_{ij}^{s} \Delta z_{ijt+s} + \nu_{ijt}, \\
    f_{jit} &= \alpha_{ji} + \gamma_{ji}^{1} sc_{jit} + \gamma_{ji}^{2} bfp_{jit} + \gamma_{ji}^{3} \delta_{jit} + \sum_{s=-S}^{S} \Phi_{ji}^{s} \Delta z_{jit+s} + \nu_{jit},
\end{align*}
\]

where the error terms are given by $\nu_{ijt}$ and $\nu_{jit}$ and the parameter’s of interest are given by $\gamma_{ij}^{1} - \gamma_{ij}^{3}$ and $\gamma_{ji}^{1} - \gamma_{ji}^{3}$ for fronthaul and backhaul transport markets, respectively.

Standard panel data estimation of this system is complicated by the potential nonstationarity of various time series in the data, which may mask the structural equilibrium relationships implied by the theoretical model. To this end, we proceed with a thorough investigation of each of the time series in the system, including several tests for panel unit roots as well as panel cointegration. Following these tests, the estimation of the demand and pricing relations proceeds equation by equation using Pedroni’s group-mean Panel DOLS and FMOLS estimators. The use of these techniques to estimate the cointegration relations addresses concerns of endogeneity of right hand side variables. As noted by Hamilton [1994], the potential for spurious regressions due to unit roots is accounted for by the existence of a cointegration relation. Furthermore, given cointegration, a system of equations with i.i.d. errors can, under certain conditions, be estimated via equation by equation OLS, despite the potential simultaneous equations bias. According to Pedroni [2001], OLS estimates may still suffer from a second order bias which warrants the use of group-mean panel estimators.
Thus, after checking for the existence of panel unit roots in each of the time series and establishing the existence of cointegration relations, we estimate each equation via the DOLS and FMOLS estimators.

4 Data

The data that are used 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 sales prices for the US, 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 US), Asian GDP is controlled for via the cumulative GDP of Japan, South Korea, India and Indonesia, while the Asian sales price is controlled for via the average CPI of Japan, South Korea, India, Indonesia, and China. The data on regional shipping capacity have been obtained from the United Nations Conference on Trade and Development (UNCTAD) database. Market access costs in the Trans-Pacific and Trans-Atlantic markets are given by the bunker fuel prices in Los Angeles and Philadelphia, respectively, and have been obtained from the Shipping Intelligence Network.\textsuperscript{22} Data on the left-hand side variables, 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. The majority of the data are observed at quarterly or annual frequencies and span a time frame from the fourth quarter of 1995 to the fourth quarter of 2009.\textsuperscript{23} While all variables used in the estimation of the empirical model are seasonally adjusted and in logged form\textsuperscript{24}, the seasonally unadjusted level data on these variables are summarized in Tables 1 and 2.

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

\textsuperscript{22}Bunker fuel prices for the Asia-EU market were unobtainable. Thus, we have chosen for these prices to be equal to the average between the available two measures. This, however, introduces artificial cross-
Table 1: Summary Statistics - Trade and Unit-Specific Trade Costs

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Cargo Flow (million TEUs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fronthaul Qty: Trans-Pacific Market</td>
<td>56</td>
<td>2,412</td>
<td>942.4</td>
<td>895.1</td>
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<td>Backhaul Qty: Trans-Pacific Market</td>
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<td>1,169</td>
<td>352.2</td>
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<td>Fronthaul Qty: Asia-EU Market</td>
<td>48</td>
<td>1,556</td>
<td>587.4</td>
<td>810.2</td>
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</tr>
<tr>
<td>Backhaul Qty: Asia-EU Market</td>
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<td>843.5</td>
<td>193.2</td>
<td>468.7</td>
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<td>Fronthaul Qty: Trans-Atlantic Market</td>
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<td>528.2</td>
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<td>348.4</td>
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<td>Backhaul Qty: Trans-Atlantic Market</td>
<td>56</td>
<td>423.3</td>
<td>76.45</td>
<td>320.8</td>
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<td>Regional Freight Rates ($ per TEU)</td>
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<td>Fronthaul Rate: Trans-Pacific Market</td>
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<td>1,717</td>
<td>226.3</td>
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<td>Backhaul Rate: Trans-Pacific Market</td>
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<td>Fronthaul Rate Trans-Atlantic Market</td>
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<td>Backhaul rate: Trans-Atlantic Market</td>
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<td>1,117</td>
<td>255.6</td>
<td>778</td>
<td>1,637</td>
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</tbody>
</table>

Sources: Containerized Cargo Flow data - Drewry and Freight Rate data - Containerisation International

include the Trans-Pacific Market which is defined as the container cargo flow between the US and Asia, the Trans-Atlantic Market defined as the container cargo flow between the US and EU, and the Asia-EU Market including container trade flows between these two regions. The mean values of container cargo flow and freight rates, listed in Table 1, indicate large trade imbalances and freight rate differentials in the Trans-Pacific as well as Asia-EU market. The Trans-Atlantic market, however, exhibits less distinguished imbalances, on average.

Figures 2(a)-2(f) provide additional evidence in support of these initial observations. The figures depict the unadjusted freight rates and containerized trade flows for each transport market pair. Imbalances and differentials, present in the Trans-Pacific and Asia-EU market pairs, are large with a clearly defined net exporting and net importing region. That is, the Trans-Pacific market pair between the US and Asia, exhibited by Figures 2(a) and sectional dependencies that, if adjusted, destroy all variation of this measure.

\textsuperscript{23}Data on market shipping capacity are only available at annual frequency and have been linearly interpolated to quarterly frequency.

\textsuperscript{24}Seasonal adjustments have been performed via the X11 routine. This standard procedure recognizes linear interpolation and leaves the interpolated variables unchanged.
2(b), clearly shows that the trade route from Asia to the US constitutes the fronthaul transport market, $ij$, for the majority of the sample period, while the route from the US to Asia constitutes the backhaul, $ji$, for the majority of the sample. Similarly, the market pair between Asia and the EU, which is depicted in Figures 2(c) and 2(d), has a clearly defined fronthaul transport market, $ij$, where trade is facilitated from Asia to the EU and a subsequent backhaul, $ji$, where trade is facilitated from the EU to Asia. The freight rate differentials in these markets mirror the clear distinction between fronthaul and backhaul trade flows.

In contrast, Figures 2(e) and 2(f) show that the Trans-Atlantic market pair exhibits switching trade imbalances that roughly coincide with switching freight rate differentials. In particular, the figures reveal that initial observations point to roughly balanced bilateral trade between the US and EU, where fronthaul and backhaul transport markets are not clearly defined until the second quarter of 1997. In line with the theoretical model, the freight rate differential is initially relatively small and declines over this time period. In contrast, observations from the second quarter of 1997 until the second quarter of 2007 exhibit a much larger trade imbalance, where westbound EU to US trade is 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 westbound EU to US trade becomes much larger than the backhaul freight rate charged on eastbound US to EU trade reflecting the reallocation of marginal joint costs towards the fronthaul transport market. At the end of the sample period, however, the trade imbalance switches and the eastbound US to EU trade becomes the fronthaul transport market. Freight rates adjust to this changing trade pattern, so that the freight charged on eastbound US to EU trade becomes the larger fronthaul freight rate by the end of the sample. 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.
Figure 2: Trade Imbalances and Freight Rate Differentials
Table 2: Summary Statistics - Trade and Freight Rate Determinants

<table>
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<tr>
<th>VARIABLES</th>
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<tbody>
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<td>Regional GDP (trillion US$)</td>
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<tr>
<td>US GDP</td>
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<td>13.21</td>
<td>1.454</td>
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<td>Euro-Area (19) GDP</td>
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<td>11.05</td>
<td>0.914</td>
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<td>Asia GDP</td>
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<td>9.696</td>
<td>1.410</td>
<td>7.952</td>
<td>12.31</td>
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<td>Regional CPI (2010=100)</td>
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<td>US CPI</td>
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<td>84.36</td>
<td>9.024</td>
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<td>Euro-Area (19) CPI</td>
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<td>86.51</td>
<td>7.423</td>
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<td>Asia CPI</td>
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<td>76.92</td>
<td>10.42</td>
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<td>Shipping Capacity - Trans-Atlantic Market</td>
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<td>29,243</td>
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<td>Bunker Fuel Prices ($ per ton)</td>
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<tr>
<td>Bunker Fuel Price West Coast (Los Angeles)</td>
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<td>212.8</td>
<td>141.4</td>
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<td>Bunker Fuel Price East Coast (Philadelphia)</td>
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<td>210.5</td>
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<td>Containerized Trade Imbalance</td>
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<td>Imbalance - Trans-Pacific Market</td>
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<td>-0.523</td>
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<td>48</td>
<td>-0.574</td>
<td>0.0973</td>
<td>-0.733</td>
<td>-0.405</td>
</tr>
<tr>
<td>Imbalance - Trans-Atlantic Market</td>
<td>56</td>
<td>-0.808</td>
<td>0.112</td>
<td>-1.000</td>
<td>-0.604</td>
</tr>
</tbody>
</table>

Sources: GDP & CPI - OECD, Bunker Fuel Prices - Shipping Intelligence Network, Market Shipping Capacity - UNCTAD and Trade Imbalance - Drewry

The remaining data consists of time series observations for variables that are used as aggregate income shifters, sales price controls and shipping cost factors in the estimation. Table 2 presents the summary statistics on the GDP, CPI, market shipping capacities, bunker fuel prices and trade imbalance data.

5 Results

In this section, we present the empirical results. First, we apply multiple panel unit root tests to all of the individual time series used in the estimation. Several of these tests point to non-stationarity of various time series in the data and integration of order one. Given the
non-stationarity, we then proceed with tests for panel cointegration developed by Pedroni et al. [1999] and Pedroni [2004]. The tests produce supporting evidence of the existence of cointegration. Based on these results, the cointegration relations are estimated and the structural demand and pricing relationships of the container shipping industry that govern the long-run equilibrium of containerized trade are obtained. These estimates point to the simultaneity between trade and unit-specific trade costs. The estimation is carried out via the group-mean Panel FMOLS and DOLS estimators developed by Pedroni [2000] and Pedroni [2001], respectively. We conclude this section with a discussion and interpretation of the estimated cointegration relations and use the specific estimates to simulate the long-run equilibrium impact of several permanent shocks, such as the reduction of carrier market power, on trade and freight rates distinguishing between fronthaul and backhaul transport markets.

5.1 Unit root tests

We have performed several panel unit root tests on each of the time series that are incorporated in the estimation of the structural model of trade and transportation. The panel unit root tests employed include the Levin-Lin-Chu (LLC) test developed by Levin et al. [2002] as well as Phillips-Perron (PP) and augmented Dickey-Fuller (ADF) tests developed by Choi [2001].\textsuperscript{25} There are a number of tests available to examine the existence of panel unit roots. The specific tests chosen for this analysis are built on assumptions that best fit the data employed in this study. Some of these assumptions, which are common among these tests, 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.\textsuperscript{26}

\textsuperscript{25}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.

\textsuperscript{26}Other commonalities include the fact that all three tests maintain the null hypothesis that the time series exhibits a panel unit root. However, the alternative hypotheses vary across these tests. That is, 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.
The results of the panel unit root tests are given in Table 3 and are presented for the levels as well as first differences of each time series. 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, shipping capacity, and bunker fuel prices. Considering the panel unit root tests on the differenced data no time trends were included in the regression equations. The issue of lag selection has been addressed with the Hannan-Quinn Information Criterion (HQIC). Furthermore, none of the time series were demeaned prior to any of the tests.\textsuperscript{27}

As the test-statistics reported in Table 3 suggest, we have strong evidence that at least 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, CPI and exporter/importer GDP. In contrast, 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, CPI and exporter/importer GDP are, in fact, integrated of order one, while freight rates may be integrated of order one.

Concerning the pricing relations, all of the tests provide strong evidence that the level of market shipping capacity and the trade imbalance reflect a panel unit root, while the evidence

\textsuperscript{27}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 US 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 GDP. Furthermore, bunker fuel prices for the Asia-EU market pair are generated by averaging the available price measures for the other two market pairs in the panel. Thus, exact cross-sectional dependence for these time series is an artifact of the data generation, 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 3: Panel Unit Root Tests

<table>
<thead>
<tr>
<th>Variables</th>
<th>Levels</th>
<th>1st Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LLC</td>
<td>Fisher-DF</td>
</tr>
<tr>
<td><strong>Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity $ (q_{ijt})$</td>
<td>-2.68***</td>
<td>2.00</td>
</tr>
<tr>
<td>Freight Rate $ (f_{ijt})$</td>
<td>-2.46***</td>
<td>-3.58***</td>
</tr>
<tr>
<td>Sales Price $ (p_{it})$</td>
<td>-0.54</td>
<td>-1.84**</td>
</tr>
<tr>
<td>Exporter/Importer GDP $ (y_{it}/y_{jt})$</td>
<td>1.54</td>
<td>0.85</td>
</tr>
<tr>
<td><strong>Pricing Relations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fronthaul Freight Rate $ (f_{ijt})$</td>
<td>-3.54***</td>
<td>-2.59***</td>
</tr>
<tr>
<td>Backhaul Freight Rate $ (f_{jit})$</td>
<td>-1.32*</td>
<td>-2.37***</td>
</tr>
<tr>
<td>Market Shipping Capacity $ (sc_{ijt})$</td>
<td>1.82</td>
<td>1.62</td>
</tr>
<tr>
<td>Bunker Fuel Prices $ (bp_{p_{ijt}})$</td>
<td>-4.21***</td>
<td>-3.38***</td>
</tr>
<tr>
<td>Trade Imbalance $ (\delta_{ijt})$</td>
<td>0.28</td>
<td>0.32</td>
</tr>
</tbody>
</table>

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 *** (**, *).

of a panel unit root concerning freight rates 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. Contrary to these mixed findings, with exception of market shipping capacity, all of the tests suggest that the first difference of all variables is stationary at the 1% significance level. Even for market shipping capacity, both of the Fisher-type tests reject the null of a panel unit root at the 10% level. Based on these tests on the pricing relations variables, we conclude that market shipping capacity and the trade imbalance are also integrated of order one, while fronthaul and backhaul freight rates 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]. That is, we have found evidence of panel unit root processes of order one, which point to the possible use of cointegration techniques that allow for super-consistency and unbiased coefficient estimates, despite potential concerns of endogeneity or non-stationarity of the individual data series. Specifically, we take advantage of the information contained within the cointegration equation and estimate the long-run structural relations projected by the static equilibrium model we have developed.

5.2 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. Since the panel employed for the demand and pricing relations estimations includes only a short cross-sectional dimension and a medium length time dimension, rejection of the null hypothesis of no cointegration of any test gives evidence for the existence of cointegration relations. 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.

The results of these tests are presented in Table 4 and provide supporting evidence of the existence of cointegration relations between trade, trade costs, trade prices and aggregate income on the demand side and trade costs, the trade imbalance, as well as market power and shipping cost factors on the supply side. In particular, on the demand side, five out of the seven tests excluding a time trend reject the null hypothesis of no panel cointegration at the 5% level, while the Panel $\rho$-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

\footnote{As Pesaran et al. [2001] point out the existence of 'level relationships' is not dependent on all variables being integrated of order one.}
Table 4: Panel Cointegration Tests

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Demand (1)</th>
<th>Demand (2)</th>
<th>Fronthaul Pricing (3)</th>
<th>Fronthaul Pricing (4)</th>
<th>Backhaul Pricing (5)</th>
<th>Backhaul Pricing (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel $\nu$-statistic</td>
<td>2.02**</td>
<td>0.83</td>
<td>1.37*</td>
<td>0.37</td>
<td>2.26**</td>
<td>1.39*</td>
</tr>
<tr>
<td>Panel $\rho$-statistic</td>
<td>-1.59*</td>
<td>-0.78</td>
<td>-0.54</td>
<td>0.12</td>
<td>-1.40*</td>
<td>-1.00</td>
</tr>
<tr>
<td>Panel pp-statistic</td>
<td>-2.02**</td>
<td>-1.57*</td>
<td>-0.77</td>
<td>-0.31</td>
<td>-1.68**</td>
<td>-1.74**</td>
</tr>
<tr>
<td>Panel adf-statistic</td>
<td>-1.88**</td>
<td>-1.78**</td>
<td>-0.89</td>
<td>-0.49</td>
<td>-1.44*</td>
<td>-1.47*</td>
</tr>
<tr>
<td>Group $\rho$-statistic</td>
<td>-0.78</td>
<td>0.8</td>
<td>0.07</td>
<td>0.70</td>
<td>-0.79</td>
<td>-0.42</td>
</tr>
<tr>
<td>Group pp-statistic</td>
<td>-1.83**</td>
<td>-1.08</td>
<td>-0.55</td>
<td>-0.02</td>
<td>-1.55*</td>
<td>-1.50*</td>
</tr>
<tr>
<td>Group adf-statistic</td>
<td>-2.16**</td>
<td>-1.88**</td>
<td>-0.83</td>
<td>-0.30</td>
<td>-1.42*</td>
<td>-1.40*</td>
</tr>
</tbody>
</table>

Trend | no | yes | no | yes | no | yes |

Notes: All statistics are normalized to be distributed N(0, 1). For the $\nu$-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.

thus, the demand for transport, as a function of unit-specific trade costs, the domestic sales price and exporter as well as importer aggregate incomes.

Concerning the pricing relations, 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 (only the Panel $\nu$-statistic rejects the null of no cointegration at the 10% level), the existence of a time trend exclusive cointegration relation governing the backhaul pricing relation is strongly supported by six out of seven tests that reject the null in favor of the alternative hypothesis at either the 5% or 10% significance level. In contrast, the evidence concerning the existence of time trend inclusive cointegration relations is less convincing 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. Proceeding with the time series analysis, we estimate these cointegration relations to determine the long-run dynamics that hold around the trade and transportation equilibrium.
5.3 **Cointegration Relations Estimation**

As noted earlier, the existence of cointegration among the unit root processes leads to super consistency of the OLS estimates. However, as several studies have pointed out, the endogeneity takes hold in a second order bias that can have significant influence, despite this super-consistency. Several estimators have been proposed 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 a ‘between-dimension’ FMOLS estimator and demonstrates that it performs well for small samples. In line with the literature and to provide a more complete analysis, we employ and report the results of the group-mean Panel DOLS estimator developed by Pedroni [2001] as well as the group-mean Panel FMOLS estimator developed by Pedroni [2000].

Guided by the empirical model and following the cointegration tests, we specify the estimation of the cointegration relations to include panel specific fixed effects, but exclude market specific time trends. The results of the group-mean panel DOLS estimator are given in Table 5, while the results of the group-mean panel FMOLS estimator are presented in Table 6. Generally, we find statistically significant coefficient estimates for all cointegration relations. In fact, across both estimators all but two coefficient estimates are statistically significant at either the 1% or 5% significance level and all estimates match the expected signs. That is, on the demand side, unit specific trade costs as well as domestic sales prices exhibit a negative correlation with the level of trade, while aggregate incomes exhibit a positive correlation with international trade. Concerning the determination of long-run equilibrium freight rates, despite the variation in coefficient magnitude, both fronthaul and
Table 5: Cointegration Relations - group-mean panel Dynamic OLS estimator

<table>
<thead>
<tr>
<th>Variables</th>
<th>Demand (1)</th>
<th>Demand (2)</th>
<th>Fronthaul Pricing (3)</th>
<th>Fronthaul Pricing (4)</th>
<th>Backhaul Pricing (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight Rate ((f_{ijt}))</td>
<td>-0.044</td>
<td>-0.044</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(-1.350)</td>
<td>(-1.350)</td>
<td>(-1.350)</td>
<td>(-1.350)</td>
<td>(-1.350)</td>
</tr>
<tr>
<td>Sales Price ((p_{it}))</td>
<td>-0.597**</td>
<td>-0.597**</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(-2.374)</td>
<td>(-2.374)</td>
<td>(-2.374)</td>
<td>(-2.374)</td>
<td>(-2.374)</td>
</tr>
<tr>
<td>Exporter GDP ((y_{it}))</td>
<td>0.927***</td>
<td>0.927</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(3.544)</td>
<td>(-0.280)</td>
<td>(-0.280)</td>
<td>(-0.280)</td>
<td>(-0.280)</td>
</tr>
<tr>
<td>Importer GDP ((y_{jt}))</td>
<td>1.189***</td>
<td>1.189</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(4.874)</td>
<td>(0.775)</td>
<td>(0.775)</td>
<td>(0.775)</td>
<td>(0.775)</td>
</tr>
<tr>
<td>Shipping Capacity ((sc_{ijt}))</td>
<td>-</td>
<td>-</td>
<td>-0.733***</td>
<td>-0.425***</td>
<td>-0.425***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(-4.667)</td>
<td>(-4.405)</td>
<td>(3.201)</td>
</tr>
<tr>
<td>Bunker Fuel Prices ((bf_{ijt}))</td>
<td>-</td>
<td>-</td>
<td>0.449***</td>
<td>0.121***</td>
<td>0.121***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(5.543)</td>
<td>(2.657)</td>
<td>(-7.154)</td>
</tr>
<tr>
<td>Trade Imbalance ((\delta_{ijt}))</td>
<td>-</td>
<td>-</td>
<td>0.352**</td>
<td>-0.307***</td>
<td>-0.307***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2.322)</td>
<td>(-3.515)</td>
<td>(-7.550)</td>
</tr>
</tbody>
</table>

Lags and Leads | 1 | 1 | 1 | 1 | 1  
Panels | 6 | 6 | 3 | 3 | 3  
Observations | 320 | 320 | 160 | 160 | 160  
Coefficient Hypothesis | [0,0,0,0] | [0,0,1,1] | [0,0,0,0] | [0,0,0,0] | [-0.733, 0.449, -0.352]  

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.

backhaul pricing relations show that a persistent rise in access costs, due to increases in bunker fuel prices, leads to permanent increases in freight rates. In contrast, a permanent increase in competition via larger market shipping capacity is associated with a long-run decline in fronthaul and backhaul freight rates. Furthermore, both estimators illustrate that persistent change in joint costs has varying effects on fronthaul and backhaul transport rates.

Considering the estimated demand relation, reported in column (1) in Tables 5 and 6, we find consistency of coefficient estimates across the DOLS and FMOLS estimators. While the coefficient on freight rates turns up insignificant for the DOLS estimator, its magnitude of -0.044 is very similar to the FMOLS estimate of -0.058, which is statistically significant at the 1% 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 containerized trade by 0.058%, on average. This very inelastic response of containerized trade to a change in unit-specific trade costs is consistent with 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.\textsuperscript{29} Given our data, a 1% permanent increase in freight rates corresponds with a $12.5 rise in average freight rates, or a $15.4 and $9.7 increase in average fronthaul and backhaul freight rates, respectively. Based on our estimate and data, this persistent increase in freight rates would coincide with a long-run decrease of average trade by 670,093 containers, or 869,265 and 470,921 containers in fronthaul and backhaul transport markets, respectively. Taking the potential range of average container cargo values into account, these permanent reductions in the volume of trade lead to a long-run decline of the average value of trade ranging from $6.7 billion to $1.2 trillion, or $8.7 billion to $1.6 trillion in fronthaul transport markets and $4.7 billion to $0.8 trillion in backhaul transport markets.\textsuperscript{30}

Similar to this finding, the DOLS and FMOLS estimators also show an inelastic long-run response of international trade to a change in sales prices. Coefficient estimates range from -0.340 (FMOLS) to -0.597 (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 0.340%-0.597% long-run reduction of international containerized exports by the region experiencing the price shock.

Additionally, the results show that long-run increases in economic mass 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. Specifically, the DOLS estimates suggest that a permanent 1% increase in exporter GDP raises containerized

\textsuperscript{29}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].

\textsuperscript{30}The substantial range concerning these effects stems from the considerable range in container cargo values. According to Rodrigue et al. [2013], the average retail values of a forty foot container can range from $20,000 to $3.6 million depending on the traded product.
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 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. One common prediction of the gravity model [see, for example, Anderson and van Wincoop, 2003] is that the effects of exporter and importer economic mass on trade are theoretically equal to unity. In column (2) of Tables 5 and 6, we test this hypothesis and find strong evidence in support of it. Specifically, based on the DOLS coefficient estimates, we fail to reject the null hypothesis that the long-run equilibrium effects of importer and exporter GDP on containerized international trade are unit elastic at any significance level. The same is true for the FMOLS estimates at the 1% significance level.

Considering the cointegration relations underlying the supply side of the international transport market in more detail, we have to differentiate between fronthaul and backhaul markets. In Tables 5 and 6, the fronthaul and backhaul pricing relations are given by columns (3) and (4), respectively. In particular, the estimates of the fronthaul pricing relation reveal that, in the long-run, a 1% permanent increase in market shipping capacity leads to a persistent decline of the fronthaul freight rate ranging from 0.509% (FMOLS) to 0.733% (DOLS). Both of these estimates are statistically significant at the 1% level. In comparison to these fronthaul estimates, the coefficient estimates of the backhaul pricing relation, which are also statistically significant at the 1% level, point to a smaller response of international freight rates charged in backhaul transport markets. While the DOLS estimator predicts only a 0.425% long-run decline in the backhaul freight rate in response to a persistent 1% increase in market shipping capacity, the FMOLS estimator suggests only a 0.342% decline of backhaul freight rates in the long-run.

Observing these differences in magnitude across coefficient estimates, we repeat the estimation of the backhaul pricing relation testing the hypotheses of equality across fronthaul and backhaul coefficient estimates. The results are given in column (5) of Tables 5 and 6.
Table 6: Cointegration Relations - group-mean panel Fully Modified OLS estimator

<table>
<thead>
<tr>
<th>Variables</th>
<th>Demand</th>
<th>Fronthaul Pricing</th>
<th>Backhaul Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Freight Rate ($f_{ijt}$)</td>
<td>-0.058**</td>
<td>-0.058**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(-2.395)</td>
<td>(-2.395)</td>
<td></td>
</tr>
<tr>
<td>Sales Price ($p_{it}$)</td>
<td>-0.340**</td>
<td>-0.340**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(-1.963)</td>
<td>(-1.963)</td>
<td></td>
</tr>
<tr>
<td>Exporter GDP ($y_{it}$)</td>
<td>0.632***</td>
<td>0.632**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(3.397)</td>
<td>(-1.975)</td>
<td></td>
</tr>
<tr>
<td>Importer GDP ($y_{jt}$)</td>
<td>1.326***</td>
<td>1.326*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(6.954)</td>
<td>(1.710)</td>
<td></td>
</tr>
<tr>
<td>Shipping Capacity ($sc_{ijt}$)</td>
<td>-</td>
<td>-</td>
<td>-0.509***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(-4.413)</td>
</tr>
<tr>
<td>Bunker Fuel Prices ($bf_{p_{ijt}}$)</td>
<td>-</td>
<td>-</td>
<td>0.296***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(5.841)</td>
</tr>
<tr>
<td>Trade Imbalance ($\delta_{ijt}$)</td>
<td>-</td>
<td>-</td>
<td>0.140</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1.404)</td>
</tr>
</tbody>
</table>

Panels 6 6 3 3 3
Observations 320 320 160 160 160
Coefficient Hypothesis [0,0,0,0] [0,0,1,1] [0,0,0,0] [0,0,0,0] [-0.509, 0.296, -0.140]

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.

and reveal that the differences in fronthaul and backhaul coefficient estimates are, indeed, statistically significant for all variables. Concerning the coefficient estimates on market shipping capacity, this finding implies that an increase in competition among carriers has a statistically significantly smaller effect on the freight rates charged in backhaul compared to fronthaul transport markets. This finding is intuitive. Since backhaul markets are by definition subject to excess capacity, an increase in market shipping capacity should have a smaller effect on transport rates in backhaul markets than in fronthaul markets where capacity allocation is binding and carriers can exercise larger market power in setting fronthaul rates.

The coefficient estimates on bunker fuel prices suggest that a permanent increase in access costs raises both fronthaul and backhaul freight rates in the long-run. Specifically, we
estimate that the long-run positive effects of a persistent 1% rise in bunker fuel prices on fronthaul freight rates vary between 0.449% (DOLS) and 0.296% (FMOLS), both of which are statistically significant at the 1% level. In contrast, the DOLS (FMOLS) estimator predicts that a 1% permanent increase in bunker fuel prices in backhaul transport markets leads to only a 0.121% (0.112%) permanent increase in backhaul freight rates. Again, column (5) of Tables 5 and 6 illustrates that these differences in coefficient estimates are statistically different at the 1% significance level.

In order to capture the role that marginal joint costs play in the determination of fronthaul and backhaul unit-specific trade costs, the estimation of the fronthaul and backhaul pricing relations includes the trade imbalance. While the DOLS coefficient estimate on the imbalance term for the fronthaul pricing relation is statistically significant at the 5% level, the FMOLS estimate is not statistically different from zero. Inference on the statistically significant DOLS estimate suggests that a persistent 1% increase in the trade imbalance leads to a permanent 0.352% rise in fronthaul transport costs. This finding reflects the fact that increases in the trade imbalance correspond to a reallocation of marginal joint costs towards the fronthaul market. In contrast to this finding, estimations of the pricing relation in backhaul markets demonstrate that a permanent 1% increase in the trade imbalance leads to a statistically significant reduction of long-run equilibrium backhaul freight rates that ranges from 0.307% (DOLS) to 0.446% (FOMLS) depending on the estimator. Again, this finding can be explained by the reallocation effect. As the trade imbalance grows, the allocation of the marginal joint costs predominately falls onto fronthaul rather than backhaul markets leading to a reduction of backhaul freight rates. This finding highlights 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.

Overall, the estimation of the demand and pricing relations establishes the simultaneity between trade and transportation costs that is often ignored in models of trade. Furthermore, the estimated pricing relations, which reflect the long-run equilibrium relationships between
trade costs, the trade imbalance, the transport market structure and shipping cost factors, highlight the potential for maritime transit policy to reduce trade cost and stimulate the growth of international trade. However, the differences in coefficient estimates between fronthaul and backhaul markets also suggest that such policies may have varying effects on trade facilitated in different transport markets. One example of such a policy might be the StrongPorts initiative by the Maritime Administration of the Department of Transportation. Based on our results, the long-term effects of a policy, such as the StrongPorts initiative, as well as shocks to market structure or shipping cost factors on containerized international trade can be simulated.

5.4 Simulation

Taking into account the simultaneity of trade and transportation costs introduced by the transport sector, Table 7 gives the simulated long-term structural responses of trade and freight rates facilitated in a fronthaul and backhaul transport market pair to a variety of persistent supply and demand shocks. The results are presented for simulations based on the DOLS estimates only.

First, we consider the long-run effects of permanent shocks to the supply side of the international transport industry, such as persistent changes to market shipping capacity or bunker fuel prices which may directly result from maritime transit policy. Specifically, our simulations show that a permanent 10% increase in transport market pair shipping capacity, for example, leads to a persistent 7.284% reduction of freight rates and 0.321% increase of trade in fronthaul transport markets. In contrast, backhaul transport markets exhibit a 4.290% permanent reduction of freight rates and 0.189% persistent increase in trade in response to this 10% permanent rise in market shipping capacity.

Next, we consider the effects of a simultaneous persistent 10% decline in bunker fuel prices in fronthaul and backhaul transport markets. Column (2) of Table 7 reveals that fronthaul freight rates permanently decrease by 4.441%, while backhaul freight rates per-
Table 7: Simulation Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>Δsc(10%)</th>
<th>Δbfp(-10%)</th>
<th>Δyi (1%)</th>
<th>Δpi (10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FH Trade ($q_{ij}$)</td>
<td>0.321%</td>
<td>0.195%</td>
<td>0.931%</td>
<td>-5.874%</td>
</tr>
<tr>
<td>BH Trade ($q_{ji}$)</td>
<td>0.189%</td>
<td>0.055%</td>
<td>1.187%</td>
<td>-0.083%</td>
</tr>
<tr>
<td>FH Freight Rate ($f_{ij}$)</td>
<td>-7.284%</td>
<td>-4.441%</td>
<td>-0.089%</td>
<td>-2.172%</td>
</tr>
<tr>
<td>BH Freight Rate ($f_{ji}$)</td>
<td>-4.290%</td>
<td>-1.253%</td>
<td>0.077%</td>
<td>1.894%</td>
</tr>
</tbody>
</table>

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

manently decline by only 1.253%. The reductions in unit-specific trade costs coincide with a 0.195% and 0.055% long-run rise in the volume of fronthaul and backhaul containerized trade, respectively. Although the simulated long-run effects on trade are rather small, these simulations point to the potential of maritime transit policy to stimulate the persistent growth of international trade.

Lastly, we explore the effects of permanent shocks to the demand side of international transport markets. Specifically, we find that a 1% increase in country $i$’s income leads to a 0.931% and 1.187% long-run equilibrium increase of the volume of fronthaul and backhaul containerized trade, respectively. Since backhaul trade increases by more than fronthaul trade, the trade imbalance shrinks. Due to the reallocation of marginal joint costs in the presence of joint production, this permanent reduction of the trade imbalance causes fronthaul freight rates to permanently decline by 0.089% and backhaul freight rates to simultaneously increase by 0.077%. This, of course, implies that the long-term response of fronthaul trade is enhanced by the endogenously adjusting fronthaul freight rate, while the permanent response of backhaul trade is dampened by the corresponding change in the backhaul freight rate.

Another simulation that highlights not only this simultaneity between trade and transportation, but also the importance of joint production present in the international container shipping industry, concerns the long-run effects of a 10% permanent increase in country $i$’s sales price. The naive model of trade, ignoring endogenously adjusting freight rates, predicts
that a change in country $i$’s sales price should only affect country $i$’s exports. 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, while trade and transport from country $j$ to $i$ remains unaffected. However, as illustrated in column (4) of Table 7, the change in country $i$’s sales price not only causes an adjustment in country $i$’s exports and trade 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 $i$.

In fact, while fronthaul trade from country $i$ to $j$ permanently decreases by 5.874%, backhaul trade from country $j$ to $i$ also decreases by 0.083%. This feature is explained through the effects of joint production present in the container shipping industry, where carriers adjust both fronthaul and backhaul supplies in response to a change in fronthaul demand. Here, the permanent decrease in trade facilitated in the fronthaul transport market leads to a persistent reduction of the trade imbalance. This reduction of the trade imbalance causes a 2.172% 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. This reallocation of marginal joint cost, of course, simultaneously triggers the 1.894% persistent increases in the backhaul freight rates, which in turn causes a 0.083% permanent decline in backhaul trade. This simulation strongly supports the theoretical predictions laid out via the previously discussed comparative statics exercise. That is, when accounting for the simultaneity of trade and transport costs as well as the joint production present in the international container shipping industry, a permanent shock to one country’s sales prices not only reduces its exports, but imports as well.

6 Conclusion

Naturally, international trade critically depends on transport markets. The majority of previous 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 unit-specific trade costs measured by container freight rates.

We find that unit-specific trade costs are an integral part to the long-term determination of trade. More importantly, the existence of the long-run relationships between trade and trade costs on the demand as well as supply side of the international transportation markets demonstrate the endogeneity of trade costs. Moreover, the structural relations between trade costs, market structure and access cost factors on the supply side of transport create the opportunity for maritime transit policy to have real impacts on trade costs and thus, facilitate further growth of international trade. Specifically, simulations show that a permanent 10% increase in market shipping capacity leads to a 7.284% permanent decline of unit specific trade costs in fronthaul transport markets and 4.290% decline of unit specific trade costs in backhaul transport markets which coincide with a permanent 0.321% and 0.189% increase in trade facilitated in fronthaul and backhaul transport markets, respectively.

The estimation of the international transport pricing relations establishes the importance of the joint production present in the international container shipping industry and points to the necessary distinction between trade facilitated in fronthaul and backhaul transport markets. We demonstrate that the presence of joint production can explain spillover effects of an idiosyncratic shock between these transport markets. That is, our simulations show that an isolated domestic price shock not only triggers a response in the pertaining county’s exports, but also influences its imports.

Based on the findings in this study, there are various 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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