Trade Policy Outcomes in the Presence of Asymmetric Transport Costs:

Theory and Evidence*

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Abstract

As import tariffs continue to fall globally, the significance of alternative trade costs rises. This study investigates the effect of maritime trade policy on bilateral trade flows in the presence of bilateral trade imbalances. Using a partial equilibrium model of international trade and transportation, I show theoretically that the joint structure of bilateral (i.e. back and forth) transport markets causes asymmetric transport costs that lead to heterogeneous trade elasticities with respect to carrier costs. These elasticities vary systematically across fully and underutilized transport markets, across different bilateral trade imbalances and across differentiated products. To evaluate the model predictions empirically, I exploit information on an EU environmental policy which induces exogenous variation in carriers' operating costs. Investigating the policy's implications on US-EU trade, I find small variation in policy-induced treatment effects when bilateral trade is balanced. However, in the presence of trade imbalances, I find significant variation in trade effects with large reductions of trade in underutilized transport markets and for transactions involving bulky and/or heavy products. The empirical results provide robust evidence in support of the theoretical predictions. The documented heterogeneity of trade effects in response to policy shocks brings significantly different implications for developing and developed countries in the context of current commercial and environmental policies, such as the International Convention for the Prevention of Pollution from Ships (MARPOL) by the International Maritime Organization.

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Key words: Trade, Commercial Policy, Transportation, Backhaul, Liner, Container, EU Directive 2005/33/EC

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1 Introduction

Barriers to trade have been a central focus of the international trade literature for decades. Many of these trade impediments, such as tariffs and border related costs or cultural differences, have been analyzed by a multitude of studies.[1] The insights gained from historical policy changes and academic research have led to a dramatic global reduction in tariff rates and a multitude of preferential trade agreements. As the global reductions of tariffs approach a lower bound, the significance of alternative trade impediments, such as transport costs, grows [Hummels, 2007].

In recognition of these compositional changes in trade costs, the World Trade Organization (WTO) created the Trade Facilitation Agreement (TFA) in 2013. This agreement aims to expedite the movement and clearance of internationally traded goods and is currently in the ratification process.[2] According to the WTO's World Trade Report 2015, the agreement is expected to decrease total trade costs by 14.5%, on average, and increase global merchandise exports by up to $1 trillion per year. In light of this and other transport related trade policies, it becomes of central interest to consider the international transport sector and the role it plays in the determination of trade policy effectiveness. While there exists widely accepted knowledge and stylized facts concerning the effects of tariff-reducing trade policy, little is known about the efficacy of maritime transport policy and the potential heterogeneity of its outcomes across bilateral trade relations.

In this study, I analyze the effects that transportation-related commercial and environmental policy has on international trade and find that the effectiveness of such policy, indeed, systematically varies across bilateral trade flows. Careful consideration of the international transport sector points to the *backhaul problem*[3], or in other words, a potential underutilization of avail-

[1] For a comprehensive survey on this literature see, for example, Anderson and Van Wincoop [2004].

[2] Once two thirds of the WTO members have ratified TFA, the agreement will go into affect. As of May 25th, 2016, 79 out of 162 WTO members have ratified TFA.

[3] A significant share of internationally traded goods is facilitated by liner carriers that operate on strictly scheduled round trips. Naturally, the round trip production process generates at least two transport markets that can be served. While liner carriers provide a fixed shipping capacity to all markets of the round trip, the demands for transportation given by bilateral trade may be imbalanced. The joint allocation of fixed capacity in the presence of imbalanced demands for transport can result in underutilization of capacity in a given transport

able shipping capacity due to bilateral trade imbalances, as the source of this variation. More specifically, when carriers operate on strictly scheduled round trips, allocating fixed transport capacity to facilitate bilateral trade, the costs of providing this fixed capacity are inseparable between the individual transport markets and lead to the joint production of bilateral transport services. This joint production of transport services, in turn, prompts the integration of the equilibrium freight rates charged to facilitate bilateral trade. When the demands for transport are imbalanced, round trip cost allocation varies across the resulting *fronthaul* and *backhaul* transport markets[4] and causes asymmetric bilateral freight rates that respond differently to a given policy-induced change in carrier costs. In fact, comparative statics derived from the proposed theoretical model reveal that the asymmetric response of transport costs triggers heterogeneous bilateral trade effects that vary systematically across fronthaul and backhaul transport markets, at different levels of the bilateral trade imbalance and by product groups differentiated by their respective *ad valorem* transport costs.

To establish these theoretical predictions, I derive a model of transportation demand from a standard trade framework as in Hummels et al. [2009] and extend it to incorporate the supply-side of the transport sector, paying direct attention to the fact that round trip transport services are provided between pairs of countries under conditions of joint production. The incorporation of such a transport sector in the model effectively endogenizes the unit-specific trade costs captured by international freight rates. This endogeneity, along with the specific round trip structure of transport markets allows for the integration and asymmetry of bilateral transport costs. I derive the theoretical elasticities of trade with respect to various carrier costs and show that while these elasticities vary across fronthaul and backhaul transport markets when bilateral trade is imbalanced, the difference in elasticities vanishes as bilateral trade becomes balanced. In addition, these elasticities reveal that imbalanced backhaul trade of products with high *ad valorem* transport costs is more responsive to a change in carrier cost than otherwise identical trade of products with low *ad valorem* transport costs. Intuitively, these changes

market, labeled as the *backhaul problem.*

[4]Following common terminology the leg of the round trip facing higher demand is denoted as the *fronthaul*, while its counterpart, the leg of the round trip facing lower demand, is denoted as the *backhaul*.

in trade elasticities can be traced back to the asymmetric carrier cost allocation across the two round trip markets which alters the relative share of transport costs in overall trade costs making trade more or less responsive.

The empirical evaluation of these theoretical predictions rests on a difference-in-differences approach commonly used to estimate the treatment effects of exogenous policy changes. In specifying the estimation model, I incorporate the traditional gravity equation framework. Identification of the theoretically derived heterogeneous trade elasticities is achieved through the estimation of the negative US-EU trade externalities imposed by the EU low sulfur fuel requirement of 2010 that was enacted as part of EU Council Directive 2005/33/EC. According to this Directive, as of January 1st, 2010, liner carriers are forced to switch from low cost heavy fuel oils to high cost low sulfur fuels while at berth at any EU port to reduce air pollution from shipping. Anecdotal evidence suggests that this requirement imposed a 70% to 100% premium on in-port fuel costs, an estimated aggregate annual fuel cost increase of $1.3 billion [Ivanov, 2010] and a significant hike in international freight rates [Notteboom et al., 2010]. The estimation of the potentially varying effects of this exogenous policy-induced increase in carrier costs proceeds by integrating the standard difference-in-differences technique into the Poisson Pseudo-Maximum Likelihood estimator developed by Santos Silva and Tenreyro [2006]. The identification strategy exploits the exogenous rise in trade costs for US-EU bilateral trade flows relative to all other US trade and differentiates the average treatment effects along various dimension, including US containerized exports and imports, US fronthaul and backhaul transport markets, across balanced and imbalanced bilateral trade flows and across US trade of disaggregated product groups with high or low *ad valorem* transport costs.

The empirical analysis provides robust results that are consistent with the theoretical predictions. In particular, I find that the low sulfur fuel requirement, on average, causes a statistically-significant 9.9% reduction in US-EU containerized backhaul trade, while US-EU trade facilitated in fronthaul transport markets exhibits no statistically significant response.[5] Based on

[5] For the purposes of the empirical analysis, a transport market represents a fronthaul for a given month when the current value of bilateral trade facilitated in this market exceeds the current value of bilateral trade facilitated in the opposing direction.

the patterns of US trade, these findings translate into a statistically significant 8.0% reduction of US exports to EU countries and a statistically insignificant effect on US imports. Further differentiation between rather balanced and imbalanced bilateral US trade flows provides strong evidence that the differences in policy outcomes decreases as trade becomes more balanced. Lastly, the empirical results show a statistically significant difference in treatment effects across products with high and low *ad valorem* transport costs and point to additional heterogeneity concerning policy effectiveness at the disaggregated product level. In particular, I find that trade in products with high *ad valorem* transport costs declines by 17.9% and 7.7% in backhaul and fronthaul transport markets, respectively. In contrast, trade in low *ad valorem* transport cost products exhibits small and statistically insignificant reductions in fronthaul and backhaul transport markets in response to the low sulfur fuel requirement. Given the differences in current trade imbalances across low to high income countries and geographical regions, the derived implications are quite significant. In conjunction with aggregated World Bank data, my findings suggest that trade from low income countries, particularly in South Asia, will experience considerably disproportionate effects from transport-related global policies.

The present study contributes to the literature in several ways. First, the theoretical model provides an extension to a standard trade framework by integrating a transport sector that accounts for the backhaul problem.[6] Comparative statics illustrate that the effects of trade policy vary across international transport markets and that this variation is due to the reflection of the backhaul problem in the carrier cost structure. Furthermore, the empirical analysis offers novel results that exhibit the heterogeneous responses of international trade to an exogenous shock in carrier costs. Hence, the empirical findings provide evidence in support of the theoretical predictions that maritime transport policy leads to trade outcomes that vary across international transport markets, balanced and imbalanced bilateral trade flows and at the product level leading to otherwise unexplained asymmetric effects across US containerized exports and imports. Overall, the empirical results presented in this study are the first to

[6]The theoretical model complements derivations by Behrens and Picard [2011] or Ishikawa and Tarui [2015], for example.

provide quantitative evidence concerning the importance of the consideration of the backhaul problem in the formulation of trade policy.

The remainder of this paper is organized as follows: In section 2, I describe the institutional background of the liner shipping industry. This background section is complemented by the literature review of trade, transportation and the integration of the two subject areas presented in section 3. In section 4, I develop the theoretical model. The empirical model builds on these foundations and is presented in section 5. Section 6 summarizes the data employed, while section 7 gives the empirical results. Section 8 provides a summary as well as conclusion and points to potential areas of further inquiry.

2 Institutional Background

Prior to the development of a theoretical model that integrates trade and transportation via the incorporation of a carefully drafted international transport sector, it is imperative to gain a basic understanding of its workings. Since the theoretical model and empirical analysis are centered on containerized trade, this section provides some of the most relevant information pertaining to the liner shipping industry[7], its historical development and significance to international trade.

In 2006, container shipping had its 50 year anniversary. During the previous 50 years, the industry that was sparked by Malcolm McLean's historic innovation of a vessel carrying 58 trailer-truck bodies from Newark, New Jersey to Houston, Texas has rapidly grown and revolutionized international trade. As the demand for international transport of goods has risen dramatically in recent decades, world shipping capacity[8], as well as the capacity of individual vessels has grown to match this demand.[9] Based on predictions by the International Transport Forum (ITF) at the OECD (2015), this rapid growth of containerized trade is expected to

[7]According to the World Shipping Council, liner shipping encompasses all modes of high capacity transport services. Moreover, it is pointed out that liner vessels are primarily constituted of containerships justifying representation of liner shipping via the container shipping industry.

[8]By 2010, the global container shipping fleet was comprised of 4,677 vessels with a maximum capacity of 12.8 million TEU's [UNCTAD, Secretariat, 2014].

[9]While it was not uncommon for vessels to carry over 9,000 twenty-foot equivalent units (TEUs) in 2006 [Transportation Research Board, 2006], this capacity has been more than doubled by the largest container vessel, the triple E-class, capable of transporting over 18,270 TEUs per ship [Port Finance International, 2013].

continue and lead to a 400% increase in international freight transport by 2050. However, the ITF also predicts that this growth will be unevenly distributed across North Pacific and North Atlantic transport markets shifting the global patterns of trade and increasing transport distances by 12% by 2050 as well. These anticipated changes in the volume and patterns of international trade will continue to put tremendous pressure on international liner shipping and motivate research, like the present study, pertaining to this industry central to global economic development.

Just as the international transport sector has had to adjust to the ever increasing demands from trade, its regulation had to adapt as well. Recent deregulation via the Shipping Act of 1984 and Ocean Shipping Reform Act (OSRA) of 1998 has led to the restructuring of the global liner shipping industry.[10] Historically, container freight rates on various trade routes have been set by the associated conferences of carriers serving the respective trade route. But in the aftermath of OSRA, these conferences have lost some of their control over the separate markets of this industry. In 1999, for example, the Asia North America Eastbound Rate Agreement (ANERA) and the Japan US Eastbound Freight Conference (JUEFC), which previously controlled freight rates charged on transpacific trade routes, were suspended. In 2008, the EU repeal of the competition law block exemption, granted to the liner shipping conferences in EU trades, led to the termination of the Transatlantic Conference Agreement (TACA). Based on these new regulations, it is clear that the container shipping industry has lost some of its market power. However, container carriers continue to seek global alliances that influence the level of market power in international shipping and determination of international freight rates.

Recent data concerning the present state of the international shipping industry reveal that maritime transport accounts for the facilitation of over 70% of the total value of international trade [UNCTAD, Secretariat, 2014]. Within this overarching transportation industry, liner shipping represents one of the most important modes of transportation. In fact, according to the World Shipping Council, liner vessels transport about 60% of the total value of all seaborne trade. Across countries, the US was the world's largest importer and second largest exporter

[10] Fusillo [2013] finds that post-OSRA market shares have been much less stable.

Table 1: Avg. Containerized Trade and Freight Rate Imbalances

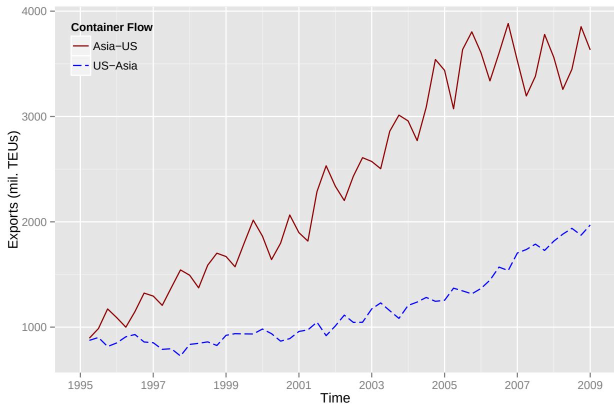
	Fronthaul		Backhaul	
Markets	Mean	Sd	Mean	Sd
Regional Cargo Flow (million TEUs)				
Transpacific Market	2,412	(942.4)	1,169	(352.2)
Asia-EU Market	1,556	(587.4)	843.5	(193.2)
Transatlantic Market	519.1	(79.51)	432.5	(90.52)
Regional Freight Rates ($ per TEU)				
Transpacific Market	1,717	(226.3)	930.8	(217.0)
Asia-EU Market	1,491	(274.8)	853.1	(167.0)
Transatlantic Market	1,385	(224.0)	1,146	(281.8)

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

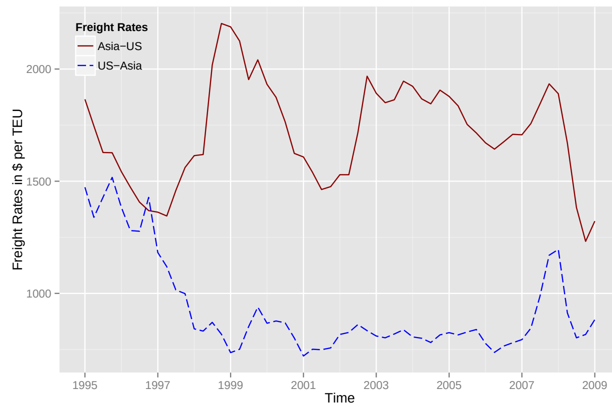
of containerized cargo, as of 2010. However, these data also show that this industry is subject to the backhaul problem stemming from the presence of the joint round trip production by container carriers. Table 1 illustrates the magnitude of this issue pertaining to the container shipping industry. The depicted average freight rates and container flows, measured in the number of Twenty-Foot Equivalent Unit (TEU) containers, facilitated on the major trading routes between Asia, the EU and the US, point to large trade imbalances that coincide with sizable average freight rate differentials in these markets.

Figures 1.1-1.4 further suggest that trade imbalances and freight rate differentials are highly correlated and persistent over time. The transpacific market, depicted in Figure 1.1, shows large and growing trade imbalances between US imports from Asia and US containerized exports to this region that correspond to growing freight rate differentials in this market, as illustrated by Figure 1.2. In contrast, the transatlantic market between the EU and US, illustrated by Figure 1.3, reveals switching trade imbalances between the two regions that largely coincide with the switching freight rate differentials depicted by Figure 1.4.

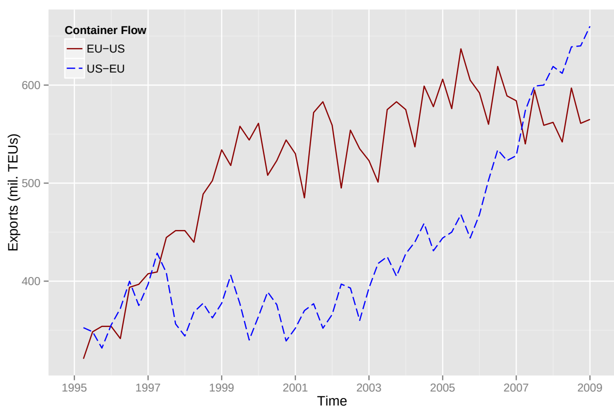
Overall, it is clear that the liner shipping industry plays an integral role in the facilitation of international trade and US trade, in particular. Aggregated data provide supporting evidence that much of this containerized international trade is subject to the backhaul problem. To the extent that freight rates matter to the determination of international trade, the correlation of freight rate differentials and trade imbalances and the resulting integration of bilateral trade



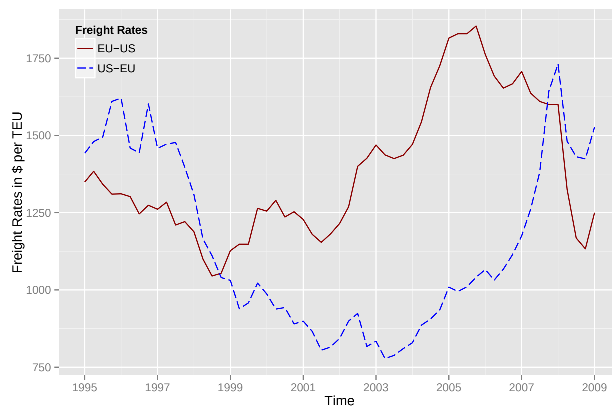
1.1: Transpacific Market: Trade Imbalances



1.2: Transpacific Market: Freight Rate Differentials



1.3: Transatlantic Market: Trade Imbalances



1.4: Transatlantic Market: Freight Rate Differentials

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

Figure 1: Containerized Trade Imbalances and Freight Rate Differentials

costs suggests that the backhaul problem plays an important role in the determination of international bilateral trade as well. The asymmetry of these unit-specific trade costs and their dependence on trade imbalances allows for the possibility of varying responses of international trade to a given change in commercial or maritime policy reforming the liner shipping industry and motivates the theoretical and empirical analyses conducted in this study.

3 Literature Review

The following section provides a basic review of the trade literature paying particular attention to studies that focus on trade costs. Within the area of trade costs, I provide a detailed summary of those studies concentrated on the international transport sector and its integration with international trade. In conclusion of this review, I illustrate the remaining gaps in the literature and point to the contributions this study offers to the field.

3.1 International Trade & Trade Costs

The driving forces underlying international trade, its welfare implications, as well as the development and analysis of policy instruments that may stimulate or hinder international trade have been a central focus of the economic literature for decades. As a result a plethora of models of international trade have been developed. While the assumptions underlying these models vary greatly[11], a common point of emphasis is the role of trade costs. In fact, regardless of the specific model of international trade, trade costs consistently manifest themselves as one of its integral determinants.[12]

While early studies have simply used geographic distance as a proxy for trade costs, many additional determinants, such as free trade agreements or colonial and cultural ties, have been identified in the more recent literature.[13] Anderson and Van Wincoop [2004] survey this literature and establish that trade costs can be divided into three main categories which include border related costs, local distribution costs and transportation costs.[14] Specifically, the authors show that about 21% of all trade costs are attributable to transportation costs. While the authors argue that is a rough estimate, there is some debate over the true effects of transport costs and trade liberalization on trade flows and growth. Baier and Bergstrand [2001], for example, find that the reduction of transport costs accounts for only 8% of total growth in

[11] Some of the more prominent theoretical models are based on assumptions, such as absolute cost advantages [Smith, 1776], Ricardian comparative 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 varying productive efficiencies [Melitz, 2003], among others.

[12] Moreover, Obstfeld and Rogoff (2000) claim that trade costs are also a critical key to solving the remaining macroeconomic puzzles identified in their study.

[13] A brief summary of these factors is presented by Head and Mayer [2013]

[14] Hummels [2001] points out that explicit trade costs such as tariffs and freight rates are more significant contributors to trade costs than implicit determinants such as common language and colonial linkages, while Hummels [2007] illustrates that in 2004, for example, transportation costs on US imports far outweighed the costs imposed by tariffs.

global trade, compared to 33% due to trade liberalization. In contrast, a more recent study by Bernhofen et al. [2016] finds that the reduction in transport costs due to containerization has had a much more significant impact on trade growth than trade liberalization efforts. In particular, the authors find that the cumulative average treatment effect (ATE) of containerization on 'North-North' trade 15 years after treatment is 1240%, compared to free trade agreements and GATT which have a cumulative ATE of 68% and 194%, respectively.

3.2 International Trade & Transport Costs

Despite the importance of transport costs in the determination of the overall barriers to trade, the subject has received surprisingly little attention historically. Recent research studies, however, have underlined the significance of the international transport sector to the determination of trade and have given the subject more careful consideration.[15] Hummels and Skiba [2004], for example, argue that transport costs are more accurately modeled as unit specific, rather than *ad valorem* trade costs, as introduced by Samuelson [1954]. Contrary to this intuitive argument, the *ad valorem* specification has been adopted by the majority of the literature[16], and, despite its shortcomings[17], distance has been used as the main variable to capture these trade costs. Few studies have focused on the direct integration of trade and transportation. Exceptions include studies by Behrens et al. [2006], Behrens and Picard [2011], Takahashi [2011], Kleinert and Spies [2011], Friedt and Wilson [2015], or Ishikawa and Tarui [2015] who have developed theoretical models that incorporate a transport sector into a variety of trade frameworks to account for the simultaneity between trade and transportation and analyze the effects of endogenous transport costs on trade.

Empirically, there are many studies that have analyzed a variety of facets concerning the relationship between trade and transportation. Friedt and Wilson [2015], for example, provide

[15] Behar and Venables [2011] offer a concise summary of the recent literature revolving around trade and transportation.

[16] One exception is the study by Feenstra and Romalis [2014] who adopt a hybrid specification of trade costs that includes both the traditional *ad valorem* and unit-specific component.

[17] Studies by Limao and Venables [2001], Combes and Lafourcade [2005], and Martinez-Zarzoso and Nowak-Lehmann [2007], for example, have uncovered a variety of issues with the geographic distance proxy and concluded that it is an overall poor instrument for transport costs.

empirical evidence of the simultaneity between trade and transportation by estimating panel co-integration relations that govern the long-run structural demand and supply equations of the international transport sector. Other studies explore the dependence of international transportation costs on the volume of trade [Martínez-Zarzoso and Suárez-Burguet, 2005, Martinez-Zarzoso and Nowak-Lehmann, 2007], or investigate its dependence on bilateral trade imbalances [Demirel et al., 2010, Jonkeren et al., 2011]. Alternatively, some studies focus on the effect of transport costs on trade [Martínez-Zarzoso et al., 2003, Martínez-Zarzoso and Suárez-Burguet, 2005, Martinez-Zarzoso and Nowak-Lehmann, 2007]. While specific coefficient estimates vary[18], the general finding of this literature is that transport costs are a significant deterrent to trade. In addition to these findings, some studies have provided reduced form estimations that show that changes in transport costs have varying effects on trade across different product categories [Martínez-Zarzoso et al., 2008], the extensive and intensive margins of trade, and across exports and imports [Bensassi et al., 2014].

However, the reduced form empirical models underlying these findings of the varying effects of transport costs on trade provide no theoretical explanation for their causes. That is, the influence of the transport market structure and its unique characteristics are unexplored in the reduced form specifications. Only a very small subset of the literature has considered the specific characteristics that are unique to the international transport sector and theoretically analyzed their impact on the distribution of economic activity and international trade, as well as their importance to trade policy [e.g. Hummels et al., 2009, Behrens and Picard, 2011, Friedt and Wilson, 2015, Ishikawa and Tarui, 2015]. Perhaps the most important one of these characteristics, as pointed out in the previous section, is the backhaul problem experienced by the liner shipping industry. As an abundant literature in the field of transport economics has pointed out, the backhaul problem is a significant issue for various transportation industries and affects not only transport pricing, market service and market access, but also regulation

[18] Possible reasons for the varying elasticity estimates include short-run versus long-run considerations [Egger, 2002], differences in the specific trade flows examined in the individual studies, or differences in the specific measures of transport costs. The measures used in the literature range from aggregate c.i.f./f.o.b. ratios to micro level survey data. As Hummels and Lugovskyy [2006] have shown, these differences may cause variability in the elasticity estimations.

outcomes [see, for example, Nicholson, 1958, Basemann and Daugherty, 1977, Rietveld and Roson, 2002, Wilson, 1994, Wilson and Beilock, 1994].

Given these findings in the transportation economics literature, the presence of the backhaul problem in the international liner shipping industry suggests that it may alter the effectiveness of maritime transport policy as well. The potential of such policies has been documented by several studies, including Bougheas et al. [1999], Clark et al. [2004], or Blonigen and Wilson [2008], which have considered the effects of infrastructure investments and port efficiency gains on international trade. In general, these studies find that increases in either infrastructure or port efficiency lowers transport costs and leads to increases in international trade. However, none of these studies considers the issues and effects arising from the backhaul problem present in the international transport sector that may lead to a variation in policy outcomes across trade flows.

In summary, the international trade literature has established the importance of transport costs to the determination of international trade and points to the international transport sector as a potential commercial policy instrument. However, up to this point this literature has failed to empirically consider the issue of the backhaul problem and its potential influence on commercial policy outcomes. Given the current state of the literature, this study contributes in several ways. First, I provide a theoretical extension to a standard trade framework by integrating a transport sector that accounts for the backhaul problem. Comparative statics based on this model illustrate that the effects of trade policy vary across international transport markets and that this variation is due to the reflection of the backhaul problem in the carrier cost structure. Second, this study offers an empirical analysis that estimates the varying responses of international trade to an exogenous shock pertaining to these carrier costs. The empirical findings provide supporting evidence for the theoretical results and show that trade policy outcomes vary across international transport markets leading to otherwise unexplained asymmetric effects exhibited by US exports and imports. That is, the empirical results presented in this study are the first to provide quantitative evidence concerning the importance of the consideration of the backhaul problem in the formulation of commercial policy and highlight the suggested implications for the global patterns and composition of trade.

4 Theory

The theoretical model developed in this section integrates trade and transportation. The solution to this model requires equilibrium in the transportation markets that facilitate bilateral trade to and from each country under conditions of the backhaul problem. The purpose of the model is to derive the response of trade to a shock in transportation costs, while accounting for the simultaneity between trade and transportation as well as the integration of bilateral transport costs. More formally, the primary focus of this section is to examine whether this response of trade is equivalent for all bilateral trade flows or whether the theory suggests systematic variation across fronthaul and backhaul transport markets. I find that maritime transport policy stimulates trade in almost all cases, albeit the magnitude of this increase in trade varies across fronthaul and backhaul transport markets and across balanced and imbalanced bilateral trade flows.

To derive these theoretical predictions, I follow the model of trade developed by Hummels et al. [2009] and provide an extension to the transport sector. In particular, I integrate a model of the international liner shipping industry that accounts, unlike Hummels et al. [2009], for the joint production by liner carriers that operate on round trips between trading countries and thereby, offer transport capacities in two transport markets that are linked by inseparable joint costs, such as expenses on crew, maintenance and repairs, as well as port and cargo dues.[19]

4.1 Demand for Transport

To begin, I derive an expression for the demand of transport from the international trade theory expressed by Hummels et al. [2009]. In this model of trade, each country, j=1,2,...,M, is

[19] This model of the transport sector follows theoretical derivations by Wilson [1994] and Wilson and Beilock [1994].

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, following Armington [1969]. The price elasticity of demand, σ, is assumed to be constant across representative consumers and greater than one. Given these assumptions, the preferences of the representative consumer in country j can be expressed by the following utility function

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

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

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 sales price of a variety from country i is represented by p_i and taken as given by carriers. 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 *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. Given these prices, the representative consumer's budget constraint can be formulated as follows

$$Y_j = q_{0j} + \sum_{i=1}^{M} p_{ij} q_{ij}, \tag{2}$$

where national income of country j is given by Y_j and the price of the local variety is expressed as $p_{jj} = p_j$, since it is assumed that there are no intra-national trade costs.

Each representative consumer maximizes utility 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, of course, also represent the demand for transport from each country i to country j and are given by the following expression;

$$q_{ij} = \left[\frac{\sigma}{\sigma - 1} (p_i \tau_{ij} + f_{ij}) \right]^{-\sigma}. \tag{3}$$

4.2 Supply of Transport

This expression for the demand of transport, given by equation (3), 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 given local sales price differences, transport demands do not have to be equal to one another. In fact, as previously noted, 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 are facilitated on strictly scheduled round trips[20] that prohibit any search and/or wait time and implies that demands for transportation in such a market pair are imbalanced.[21] Following common terminology, the leg of the round trip facing higher demand is denoted as the *fronthaul*, while its counterpart, the leg of the round trip facing lower demand, is denoted as the *backhaul*.[22]

To facilitate bilateral trade between country i and 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. In line with the current market structure of the liner shipping industry, I follow the example by Hummels et al. [2009] and model the international shipping industry to exhibit market power in each market pair ij. To accommodate this feature of the industry, the transport sector is modeled as an oligopoly consisting of $l = 1, ..., N$ symmetric carriers competing in Cournot fashion. Extending

[20] 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.

[21] 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.

[22] Given this definition, fronthaul and backhaul depend on the trade imbalance between two trading countries rather than the direction of trade flow or the starting point of a given round trip.

the given model, I assume that each carrier, l, facilitates a fraction, Q^l_{ij} and Q^l_{ji}, of total 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 and 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 addressed joint costs, $JC(K^l)$, with $JC(0) = 0$ and $\frac{\partial JC(K^l)}{\partial K^l} > 0$, that are not differentiable between the individual transport markets and depend on the shipping capacity, K^l, that is allocated to the market pair served on a given round trip. Intuitively, these costs can be viewed as, quite simply, the costs of operating a vessel of capacity $K^l \geq max(Q^l_{ij}, Q^l_{ji})$ between two locations. Therefore, each carrier's round trip costs can be expressed as follows:

$$C^l = a_{ij}Q^l_{ij} + a_{ji}Q^l_{ji} + JC(K^l) \;\; \forall l = 1, ..., N \; and \; i, j = 1, ..., M, \;\; i \neq j. \tag{4}$$

This cost structure, stemming from the joint production present in the liner shipping industry, is a key factor in the derivation of varying commercial policy effectiveness that is illustrated through some interesting comparative statics in the following subsection. Given this cost structure, each carrier chooses the profit maximizing capacity, K^l, and optimal supplies of transport, Q^l_{ij} and Q^l_{ji}, that are offered to each market on a given round trip. Specifically, each carrier's round trip profit from transporting bilateral trade between country i and country j is comprised of revenues earned in each transport market netting out the incurred access and joint costs and can be written as

$$\begin{aligned} &\max_{K^l, Q^l_{ij}, Q^l_{ji}} \Pi^l = f_{ij}Q^l_{ij} + f_{ji}Q^l_{ji} - C^l \quad \forall l = 1, ..., N \text{ and } i, j = 1, ..., M, \;\; i \neq j \\ &\text{subject to } K^l \geq Q^l_{ij}, \;\; K^l \geq Q^l_{ji}. \end{aligned} \tag{5}$$

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

$$\frac{\partial \Pi^l}{\partial Q_{ij}^l} = f_{ij} + Q_{ij}^l \frac{\partial f_{ij}}{\partial Q_{ij}^l} - a_{ij} - \lambda_1 \leq 0 \qquad \text{with} = \text{if } Q_{ij}^l > 0 \qquad \forall l = 1, ..., N \tag{6a}$$

$$\frac{\partial \Pi^l}{\partial Q_{ji}^l} = f_{ji} + Q_{ji}^l \frac{\partial f_{ji}}{\partial Q_{ji}^l} - a_{ji} - \lambda_2 \leq 0 \qquad \text{with} = \text{if } Q_{ji}^l > 0 \qquad \forall l = 1, ..., N \tag{6b}$$

$$-\frac{\partial JC(K^l)}{\partial K^l} + \lambda_1 + \lambda_2 \leq 0 \qquad \text{with} = \text{if } K^l > 0 \qquad \forall l = 1, ..., N \tag{6c}$$

$$K^l \geq Q_{ij}^l, \qquad \lambda_1 \geq 0, \qquad (K^l - Q_{ij}^l)\lambda_1 = 0 \tag{6d}$$

$$K^l \geq Q_{ji}^l, \qquad \lambda_2 \geq 0, \qquad (K^l - Q_{ji}^l)\lambda_2 = 0. \tag{6e}$$

The first-order conditions with respect to transport supplies, given by equations (6a) and (6b), can be seen as each carrier's market access conditions indicating that marginal revenues in either transport market must at least cover access costs for a given market to be served. In addition to that, each carrier's first-order condition with respect to the allocated capacity can be interpreted as the service condition. Given the fact that the Kuhn-Tucker multipliers, λ_1 and λ_2, can be thought of as the shadow prices that determine the value of an additional unit of transport supply in the respective transport markets, equation (6c) states that market pair ij is served only if the marginal joint costs of providing capacity, K^l, do not exceed the cumulative value of an additional unit of transport supply in either market.

In order to solve for the equilibrium transport supplies and capacity allocation, the transport market clearing conditions must be imposed. These conditions state that the demand for transport equals the supply of transport in both markets and can be represented by the following equations;

$$q_{ij} = \sum_{l=1}^{N} Q_{ij}^l \tag{7a}$$

$$q_{ji} = \sum_{l=1}^{N} Q_{ji}^l. \tag{7b}$$

Combining the demand for transport given by equation (3), the first-order and Kuhn-Tucker conditions given by (6a)-(6e) and the market clearing conditions represented by equations (7a) and (7b), an equilibrium solution with multiple cases can be obtained. While the details of the derivation are fairly standard, there are a few aspects of the different equilibrium cases that are important to point out.

First, given the model, any feasible equilibrium solution requires at least one binding capacity constraint, $K^l \geq Q^l_{ij}$ and/or $K^l \geq Q^l_{ji}$. This implies that any solution to this static model is characterized by full capacity utilization in at least one of the two transport markets.

Second, the set of solutions includes equilibrium cases, where optimal transport supplies and international trade are zero valued. These scenarios arise when marginal joint and/or access costs and the resulting freight rates are prohibitively high.

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, I treat the transport market facilitating trade from country i to country j as the fronthaul and trade from country j to country i as the backhaul for the remainder of the analysis.

As a matter of tractability, the remaining analysis solely focuses on cases where equilibrium transport supplies and international trade are positive in both transport markets. This limits the analysis to two potential solutions that differentiate between balanced and imbalanced bilateral trade. Naturally, the realization of a particular solution simply depends on the imbalance of the demands for internationally traded goods between two countries. Given equation (3), this demand imbalance can be represented and rewritten as follows;

$$q_{ij} \geq q_{ji} \implies p_j\tau_{ji} - p_i\tau_{ij} \geq (f_{ij} - f_{ji}), \tag{8}$$

As equation (8) 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 countries i and j, may allow carriers to choose equal transport supplies that maximize capacity utilization in both transport markets and lead to asymmetric freight rates that offset the sales price differential. In fact, it can be shown that a balanced trade equilibrium arises only if the difference in sales prices is restricted to the following interval:

$$p_j\tau_{ji} - p_i\tau_{ij} \in \left(a_{ij} - a_{ji} - \frac{\partial JC(K^l)}{\partial K^l}\ ;\ a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right), \qquad (9)$$

whereas an imbalanced bilateral trade equilibrium, with country i as the net exporter to country j, results when $p_j\tau_{ji} - p_i\tau_{ij} > \left(a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right)$. [23]

4.2.1 Case 1: Balanced Trade

For small transport demand imbalances, each carrier's equilibrium supplies of transport for a given round trip between countries i and j and the resulting equilibrium transportation rates can be derived as follows:

$$K^l = Q^l_{ij} = Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma N}{2(\sigma N - 1)}\frac{\sigma}{\sigma - 1}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij} + p_j\tau_{ji}\right)\right]^{-\sigma} \qquad (10a)$$

$$f_{ij} = \frac{\sigma N}{2(\sigma N - 1)}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_j\tau_{ji}\right) + \frac{2 - \sigma N}{2(\sigma N - 1)}p_i\tau_{ij} \qquad (10b)$$

$$f_{ji} = \frac{\sigma N}{2(\sigma N - 1)}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right) + \frac{2 - \sigma N}{2(\sigma N - 1)}p_j\tau_{ji}. \qquad (10c)$$

4.2.2 Case 2: Imbalanced Trade

Solving the model when the demands for transport are strongly imbalanced yields the following expressions for each carrier's equilibrium capacity allocation and transport supplies, as well as

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

the resulting bilateral equilibrium transportation rates:

$$K^l = Q_{ij}^l = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ij}+\frac{\partial JC(K^l)}{\partial K^l}+p_i\tau_{ij}\right)\right]^{-\sigma} \tag{11a}$$

$$Q_{ji}^l = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ji}+p_j\tau_{ji}\right)\right]^{-\sigma} \tag{11b}$$

$$f_{ij} = \frac{\sigma N}{\sigma N-1}\left(a_{ij}+\frac{\partial JC(K^l)}{\partial K^l}\right)+\frac{1}{\sigma N-1}p_i\tau_{ij} \tag{11c}$$

$$f_{ji} = \frac{\sigma N}{\sigma N-1}a_{ji}+\frac{1}{\sigma N-1}p_j\tau_{ji}. \tag{11d}$$

4.2.3 Discussion

Thus, in the balanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q_{ij}^l, Q_{ji}^l, f_{ij}, f_{ji}\right)$, of transport market pair ij facilitating balanced bilateral trade between countries i and j is described by equations (3) and (10a)-(10c). In contrast, in the imbalanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q_{ij}^l, Q_{ji}^l, f_{ij}, f_{ji}\right)$, of transport market pair ij facilitating imbalanced bilateral trade between countries i and j is described by equations (3) and (11a)-(11d). A comparison between both equilibrium cases reveals several key features that are present when trade is facilitated by an international transportation industry that is subject to the backhaul problem. Specifically, each carrier's supply of transport depends on marginal access costs, regardless of whether a given route is considered a fronthaul or backhaul, or whether trade is balanced or imbalanced. The allocation of marginal joint costs, however, heavily depends on the given trade imbalance. That is, if trade is balanced, marginal joint costs play a role in the determination of both fronthaul and backhaul equilibrium transport supplies and freight rates and therefore, lead to the integration of bilateral trade costs. In contrast, if trade is imbalanced, marginal joint costs only matter to the determination of fronthaul transportation supply and the fronthaul freight rate leading to the disintegration of bilateral trade costs.

4.3 Comparative Statics

Based on these partial equilibrium scenarios, the response of trade to a shock in carrier costs can be evaluated. Given each carrier's cost structure, two alternative transportation supply shocks can be considered. That is, both a change in marginal access costs, as well as a change in marginal joint costs can have an impact on trade. For notational convenience, I express marginal joint costs with JC' for the remainder of the analysis.

First, I consider a shock to marginal access cost. In the balanced bilateral trade case, the elasticity of trade with respect to a change in marginal access costs is given by

$$\frac{\partial q_{ij}}{\partial a_{ij}}\frac{a_{ij}}{q_{ij}} = -\sigma\frac{a_{ij}}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} < 0 \text{ if } Q_{ij} = Q_{ji}, \tag{12}$$

while in the imbalanced trade case, this elasticity can be represented as follows:

$$\frac{\partial q_{ij}}{\partial a_{ij}}\frac{a_{ij}}{q_{ij}} = -\sigma\frac{a_{ij}}{(p_i\tau_{ij} + f_{ij})}\frac{\partial f_{ij}}{\partial a_{ij}} = \begin{cases} -\sigma\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}+JC'} < 0 & \text{if } Q_{ij} > Q_{ji} \quad (fronthaul) \\ -\sigma\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}} < 0 & \text{if } Q_{ij} < Q_{ji} \quad (backhaul) \end{cases} . (13)$$

Equations (12) and (13) illustrate one of the key points of this study. When trade is imbalanced, equation (13) demonstrates that the elasticity of trade with respect to marginal access costs varies across fronthaul and backhaul transport markets. That is, while both effects depend on the elasticity of import demand with respect to import prices, marginal access costs, the local sales price and *ad valorem* trade costs, marginal joint costs only contribute to the elasticity of trade facilitated on fronthaul transport markets. Because of this critical distinction, one can show that fronthaul trade is more inelastic with respect to marginal access costs than otherwise identical backhaul trade. This result implies that when trade is imbalanced, access cost related policy outcomes are larger in backhaul relative to fronthaul transport markets. This finding is intuitive. Since marginal access costs represent a larger share of total trade costs in *backhaul* relative to *fronthaul* transport markets, backhaul trade should be more responsive than fronthaul trade to an identical change of these costs.

Proposition 1 *If equilibrium trade is imbalanced, the effect of an identical change in marginal access costs is larger for trade facilitated in backhaul transport markets than for trade facilitated in fronthaul transport markets, ceteris paribus. (A proof of this proposition is provided in Appendix I)*

In contrast, when trade is balanced, equation (12) shows that the elasticity of trade with respect to marginal access costs depends on additional terms, including the foreign sales price, p_j. Since otherwise identical fronthaul and backhaul transport markets are distinguished by this foreign sales price, its inclusion complicates the comparison of the effects on otherwise identical trade facilitated in fronthaul and backhaul transport markets. Nevertheless, several key results can be derived. First, when equilibrium trade is balanced and foreign sales prices, p_j and p_k, for example, are identical, the response of trade facilitated in the ij and ik transport markets is identical as well. Second, when trade is balanced and the foreign sales prices simultaneously approach the respective upper and lower bound of expression (9), the difference in the elasticities of trade concerning backhaul and fronthaul transport markets is smaller than the difference in elasticities derived from the imbalanced trade equilibrium. This suggests that the difference in fronthaul and backhaul policy outcomes should decrease, as the demands for transport become more balanced.

In addition to these comparisons across fronthaul and backhaul transport markets in the balanced and imbalanced bilateral trade cases, variations of the trade elasticity with respect to marginal access costs across different product varieties can be considered as well. Naturally, one would expect trade in product varieties with large values and thus, low relative transport costs to exhibit smaller responses to an identical change in marginal access costs than trade in low valued product varieties with high relative transport costs. Indeed, based on equation (13), it can be shown that when imbalanced backhaul trade is considered, the elasticity of trade with respect to marginal access costs becomes more inelastic as the sales price of a given variety increases.[24] Intuitively, this theoretical result can be explained as follows; since transport costs

[24] An extension of this result to trade in imbalanced fronthaul transport markets or the balanced trade case requires an additional nontrivial assumption on the size of the second derivative of joint costs with respect to allocated capacity.

represent a larger barrier to international trade for bulky and heavy goods, such as metals or assembled furniture, trade in these products is more responsive to change in carrier access costs than trade of small and valuable products, such as electrical machinery.

Proposition 2 *If equilibrium trade is imbalanced, the absolute value of the elasticity of trade with respect to marginal access costs in backhaul transport markets is decreasing in the sales price of any given variety. (A proof of this proposition is provided in Appendix I)*

Next, I consider the effects of a change in marginal joint costs. Again, I differentiate between the balanced and imbalanced trade cases. In the balanced case, I obtain the following expression for the elasticity of trade with respect to marginal joint costs:

$$\frac{\partial q_{ij}}{\partial JC'}\frac{JC'}{q_{ij}} = -\sigma\frac{JC'}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} \text{ if } Q_{ij} = Q_{ji}, \tag{14}$$

whereas in the imbalanced trade case this elasticity of trade can be represented as:

$$\frac{\partial q_{ij}}{\partial JC'}\frac{JC'}{q_{ij}} = -\sigma\frac{JC'}{(p_i\tau_{ij} + f_{ij})}\frac{\partial f_{ij}}{\partial JC'} = \begin{cases} -\sigma\frac{JC'}{p_i\tau_{ij}+a_{ij}+JC'} & \text{if } Q_{ij} > Q_{ji} \quad \text{(fronthaul)} \\ 0 & \text{if } Q_{ij} < Q_{ji} \quad \text{(backhaul).} \end{cases} \tag{15}$$

The interpretation of these results is very similar to previous comparative statics. That is, the elasticity of trade with respect to marginal joint costs is equal to the share of marginal joint costs relative to all trade costs, including the sales price, *ad valorem* trade costs, access costs, as well as marginal joint costs and is scaled by the price elasticity of trade. In the imbalanced trade case, equation (15) shows that the response of trade to shock in marginal joint costs strongly depends on whether a given transport market is characterized as a fronthaul or a backhaul. In particular, when trade is imbalanced, a rise in marginal joint costs triggers a reduction of trade facilitated in fronthaul transport markets, while backhaul trade is unaffected. This variation concerning the elasticity of trade with respect to marginal joint costs in the imbalanced trade case stems from the carrier cost allocation. Given sufficient imbalances concerning the demands for transport, carriers provide asymmetric transport supplies and allocate joint costs solely to the fronthaul transport market. Due to this cost allocation, a change in marginal joint costs has no impact on trade facilitated in backhaul markets.

Overall, these results show that when equilibrium bilateral trade is imbalanced, maritime transport policy outcomes strongly depend on the identification of fronthaul and backhaul transport markets, regardless of whether access or joint costs are affected.[25] However, the specific responses of trade in each of these transport markets heavily depend on the type of carrier cost affected by the given policy. Interestingly, none of the derived trade elasticities depend on the number of carriers serving a given transport market. This implies that the established variation in policy-induced trade effects is robust to changes in transport market structure.

The significance of these theoretical results is derived from the fact that trade policy, aimed at improving infrastructure to lower the costs of international carriers and reduce the unit-specific barriers to trade, can have very different effects depending on the type of carrier cost that is affected and depending on whether the change in cost applies to a fronthaul or backhaul transport market of a balanced or imbalanced bilateral trade relation. Consider, for example, US containerized trade. While US containerized exports typically represent a backhaul to a carrier's round trip in recent decades, US containerized imports typically represent a fronthaul. The theoretical results suggest that trade policy, such as the *StrongPorts*[26] initiative by the Maritime Administration or the Trade Facilitation Agreement[27] by the WTO, will lead to very different outcomes concerning US containerized imports and exports. In fact, a reduction in marginal access costs that applies to both US containerized exports and imports is expected

[25]The theoretical findings presented in this subsection are focused on policy outcomes with respect to the volume of trade, q_{ij}. All of these results continue to hold when the value of trade is considered instead. The derivation of the trade elasticities in the value case are provided in Appendix II.

[26]The basic goal of Maritime Administration's StrongPorts initiative is to provide support for the development of projects that increase port freight efficiencies. Port efficiency gains can certainly effect carrier costs, although it depends on the specific project to determine whether joint or access costs are affected.

[27]The central focus of the Trade Facilitation Agreement concerns the simplification and standardization of customs practices to expedite the movement of goods. Improved release and clearance times could potentially lower carrier access costs by reducing port handling times and terminal costs.

to have a larger effect on US exports than imports, while a reduction in marginal joint costs is expected to mainly affect US containerized imports.

5 Empirical Model

5.1 Policy Shocks

To test the theoretical propositions concerning the heterogeneity of trade policy outcomes in the presence of the backhaul problem, I build on the standard empirical model of trade, the gravity equation. This model is ubiquitous in the trade literature and has been heavily used to not only analyze the determinants of trade, but also evaluate the effects of commercial policy. Identification of the theoretically predicted systematic variation in maritime transport policy outcomes relies on an exogenous environmental regulation by the EU.

More specifically, identification of the potentially varying responses of trade to a given change in carrier costs is achieved through the low sulfur fuel requirement imposed on liner carriers through a revision of the EU Council Directive 1999/32/EC. Initial European regulation of fuel sulfur contents was imposed by the European Council via Directive 93/12/EC in March of 1993. While some of the provisions of this Directive were later repealed, the low sulfur requirements, that were in line with regulations set by the International Maritime Organization (IMO) on heavy fuel and other marine oils, were subsequently instated via Council Directive 1999/32/EC, drafted in April of 1999. The key revision of the low sulfur regulations set forth in this Directive was initiated in July of 2005 via EU Directive 2005/33/EC. This latest revision was created in response to the European Commission's strategy to reduce atmospheric emissions from seagoing ships [European Commission, 2015].[28] While there are several revisions set forth in Directive 2005/33/EC to improve air quality for the protection of human health, the one of interest to this study concerns the requirement that as of January 1, 2010, all liner carriers

[28] The strategy discusses the effects of ship emissions in the EU and proposes a variety of policies to reduce the shipping emissions and their contribution to acidification, ground-level ozone, eutrophication, health, climate change and ozone depletion.

must use fuels containing no more than a maximum level of up to 0.1% sulfur once at berth or anchorage in EU ports.[29]

This requirement marked a significant reduction in the allowable fuel sulfur content. At the time this revision went into effect, restrictions set by IMO regulations required carriers to use fuels not exceeding a maximum level of 4.5% sulfur globally and 1.5% in specific Emission Control Areas (ECAs) around Europe [Cullinane and Bergqvist, 2014]. In an assessment of impact studies, the European Maritime Safety Agency predicted that a change from 1.5% to 0.1% sulfur fuel content would result in an average fuel premium of 74% [(EMSA), 2010]. In line with this prediction, Notteboom et al. [2010] show that the long run price difference between Intermediate Fuel Oil (IFO 380) and Marine Gas Oil (MGO 0.1% sulfur) averaged around 93% between 1990 and 2008. The authors claim that, due to increasing demand and the cost of the desulfurization process, the cost of marine distillate fuels is roughly twice that of residual fuels and causes a significant increase in container freight rates. Further anecdotal evidence suggests that these increases in required fuel prices would equate to a cumulative increase of fuel costs of around $1.3 billion per year [Ivanov, 2010].[30] As such, the low sulfur fuel requirement meets the necessary condition of significantly influencing carrier costs pertaining to international shipments of US-EU trade.

The exogeneity of this change to the existing sulfur content regulations stems from the fact that its origination and implementation has been motivated by the European Commission's environmental strategy to reduce pollution from maritime shipping, rather than trade related issues. There are a few studies that have analyzed a variety of issues related to the low sulfur

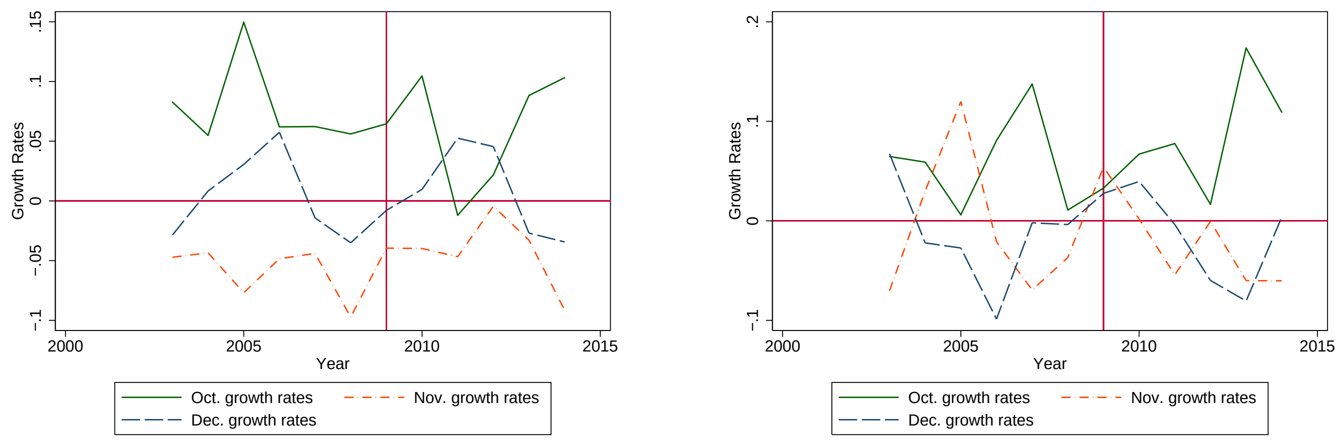
[29]There are a number of exceptions to the Directive's requirement. Most notably, if the scheduled duration of a vessel anchored at an EU port does not exceed two hours, the low sulfur fuel requirement does not apply. However, this provision tends to only be relevant to ferry services and other smaller ships, rather than large container vessels facilitating transatlantic trade. Alternatively, if a carrier agrees to completely shutdown a vessel's engines while at berth in an EU port, fuels do not have to be switched over. However, the feasibility of this alternative depends on whether a given port provides shore-side electricity from the national grid. While EU ports are encouraged to provide this service, they are not required to do so, as of January 2010. Since these exclusions reduce the burden of the low sulfur fuel requirement on the average carrier, their existence may create a potential downward bias in the estimation of treatment effects. Thus, the results can be interpreted as conservative estimates of the actual policy impact.

[30]Although there were several alternative emissions abatement technologies approved as of January 2010, all of these technologies placed a significant burden on liner carriers involved in EU trade as well [P&O Ferrymasters].

fuel requirement of Directive 2005/33/EC [see, for example, Endresen et al., 2005, Schrooten et al., 2008, Bosch et al., 2009]. However, to the best of my knowledge, there are no studies that have estimated the requirement's effects on international trade or considered the potential heterogeneity of its impact across trade facilitated in fronthaul and backhaul transport markets.

Of course, the considerable gap between the publication of EU Directive 2005/33/EC and its implementation may cause a few issues to properly identify the resulting treatment effects on US-EU trade. An immediate concern leading to the possible inflation of the estimated treatment effects may be the potential anticipatory changes in trade immediately prior to the implementation of the low sulfur fuel requirement in an attempt to avoid rising trade costs. To address this potential issue, Figures 2.1 and 2.2 display October, November, and December growth rates of US-EU trade by year. The figures show, that for both US exports and imports with treated European countries, there is no evidence of extraordinary average trade growth in 2009, indicated by the vertical line, immediately before the treatment implementation. That is, in comparison to previous years, there is no evidence of a build-up or rush to get shipments in or out prior to the implementation of the cost raising low sulfur fuel requirement annulling this potential concern.

Another issue associated with the sizable time lapse between publication and implementation of this policy may be early adjustments by international carriers that could potentially put a downward bias on the estimated treatment effects. Anecdotal evidence, however, suggests that the majority of carriers avoided pre-implementation adjustment costs by playing a waiting game in hopes of a last minute EU repeal or postponement of the low sulfur fuel requirement [Ivanov, 2010]. Refusing to yield to carrier opposition, on December 21, 2009, the EU published a statement re-enforcing the timely implementation of the low sulfur fuel requirement [European Commission, 2009] forcing the majority of non-compliant shipowners to immediately adjust their practices and nullifying this concern as well.



2.1: US Exports

2.2: US Imports

Source: *USA Trade Online* database

Figure 2: Average End-of-the-Year Monthly Growth Rates of US-EU Trade (2003-2014)

5.2 Empirical Specification

Given this identification strategy and data availability, a difference-in-differences (henceforth referred to as DID) estimator is the natural choice to evaluate the varying trade outcomes of commercial and related environmental policy. Of course, various DID specifications are available and have been used in the literature. These specifications range from indicator variables that capture the average treatment effect, to the inclusion of treatment and control group, or even panel-specific, time trends [e.g. Friedberg, 1998], which are intended to control for a violation of the parallel paths assumption. Other specifications use time varying post-treatment indicator variables in conjunction with group-specific time trends to capture the dynamic response to policy changes [e.g. Wolfers, 2006] or exclude time trends altogether and instead use time-varying pre- and post-treatment dummies for a more flexible specification [e.g. Mora and Reggio, 2012]. In this study, I employ the standard DID estimator and include a treatment indicator variable, δ_{jt}, that captures the difference in trade across treatment and control groups post-policy implementation.[31] As Bertrand et al. [2004] have shown, the standard DID estimator

[31] In the following section, I present data plots that provide evidence in support of the parallel paths assumption and dissuade the use of time trends in conjunction with the DID estimator. Nevertheless, as part of the robustness analyses, I estimate the model including treatment and control group, as well as country-specific time trends. In general, the treatment effect estimates and their statistical significance are robust to the inclusion of these time trends and the results are presented in Panels 2 and 3 of Table 6 in Appendix III.

can suffer from significant bias in the presence of serial correlation in both the dependent and dummy variable.[32] Following suggestions by Bertrand et al. [2004], standard errors are clustered at the state, rather than state-time level. For the application in this study, this implies that standard errors are, in fact, clustered at the US port-foreign country level.[33]

In-line with the majority of the empirical trade literature, the DID estimator employed in this study is incorporated into the standard gravity equation framework. In addition to the indicator variable, δ_{jt}, which captures the exogenous shock to unit-specific transport costs involving EU trade, all other trade determinants are accounted for following standard practices. In particular, economic mass is captured via total exporter and importer employment, L_{it} and L_{jt}, while the multilateral resistance terms introduced by Anderson and Van Wincoop [2003] are controlled for by means of various fixed effects, including exporter and importer, a_i and a_j, as well as time fixed effects, a_t.[34] Since the empirical analysis is focused on monthly containerized trade flowing to and from a variety of foreign countries through US ports of entry, the empirical

[32]Moreover, Donald and Lang [2007] show that biased coefficient estimates can also occur when the number of panels in a given dataset is small. This, however, is not a concern for analysis conducted in this study as the dataset includes over 1400 US port-foreign country pairs.

[33]Some concerns may arise due to the potential cross cluster correlation at more aggregated state levels. These include potential bilateral trade correlations across the US port-foreign country pairs that respond to a common shock at the US state level, as well as potential trade correlations across foreign countries that experience a common shock at the US port or state level. To address these concerns, I have re-estimated the model clustering standard errors at the US state-foreign country level, US port level, and US state level. In general, the statistical significance of coefficient estimates is robust to these variations in clustering and results are presented in Table 7 of Appendix III.

[34]Within the trade literature focused on the estimation of the gravity equation, the use of fixed effects to capture multilateral trade cost differences has rapidly evolved in recent years. The use of fixed effects commenced with the inclusion of exporter/importer dummy variables [see, e.g., Harrigan, 1996, Egger, 2000, Feenstra, 2002], and advanced to more sophisticated specifications also including bilateral fixed effects [e.g. Egger and Pfaffermayr, 2003]. The progression culminates in the use of time varying exporter and importer fixed effects, in addition to bilateral fixed effects, as in Baldwin and Taglioni [2006], for example. In this study, I estimate the average treatment effects of the low sulfur fuel requirement on US-EU trade. The estimation sample includes monthly observations of US containerized exports and imports to and from OECD and APEC countries. Since the US is the common trade partner for all bilateral trade pairs, exporter and importer fixed effects capture not only country-specific, but also bilateral-specific unobservables. While the low sulfur fuel requirement varies across foreign OECD and APEC countries, it is implemented at one specific date. Identification off of this policy, thus, prohibits the use of time-varying exporter and importer fixed effects. However, since the US is the common trade partner for all trade observations, the inclusion of time fixed effects controls for the time variation of US related multilateral trade cost differences. To ensure the robustness of the primary findings against this fixed effects specification, I also estimate the model including time-varying regional, state, or port level fixed effects that capture more disaggregated US trade related time varying unobservables. The results are presented in Table 8 of Appendix III and illustrate that the variation in trade policy outcomes is largely consistent against various fixed effects specifications.

specification also includes port fixed effects, a_p, to control for the heterogeneity across these ports.

Given the fact that the data sample only includes US trade, the use of these fixed effects not only controls for the standard time-varying national trends and time-invariant bilateral trade specific *ad valorem* trade costs, but also for systematic differences between pre- and post-treatment periods and between treatment and control group countries. To further ensure the accurate estimation of the treatment effect, I include various control variables summarized in vector Z^r_{ijt}. This collection of variables includes indicator dummies for US free trade agreements with OECD and APEC countries and an interaction term capturing any variation in the response of US-EU trade to the Great Trade Collapse (GTC) relative to all other US trade. In addition to these dummy variables, the vector Z also includes regional real US retail diesel fuel prices to control for changes in heavy fuel oil and low sulfur fuel prices, which vary over time, t, and are available at the US regional level, r.

This gives rise to the following empirical specification;

$$x_{ijpt} = exp\left(\beta_0 + \beta_1 ln(L_{it}) + \beta_2 ln(L_{jt}) + \beta_3 \delta_{jt} + \gamma ln\left(Z^r_{ijt}\right) + a_i + a_j + a_t + a_p\right)\epsilon_{ijpt}, \qquad (16)$$

where the dependent variable, x_{ijpt}, reflects the value of trade facilitated from country i to country j through US port p at time t, $ln\left(Z^r_{ijt}\right)$ represents the natural log of each element of the vector Z, and the random component is given by ϵ_{ijpt}. The key parameter of interest is given by β_3. A negative and statistically significant estimate of β_3 would indicate a decrease in US trade with an EU country relative to US trade with non-member countries due to the implementation of the low sulfur fuel requirement.

6 Data

The data employed in the estimation of this empirical model are comprised of a number of variables obtained from several different sources. The main time series of interest, and dependent variable in the empirical model, is given by US containerized maritime bilateral trade with the majority of OECD and APEC countries[35] at the seaport-of-entry level. The data were obtained from the *U.S. Census Bureau, USA Trade Online* database and include monthly observations from January of 2003 until February of 2015. This dataset provides the unique opportunity to closely identify fronthaul and backhaul transport markets facilitating US trade; an identification that would be lost at national or yearly aggregation levels. *USA Trade Online* includes a variety of ports with vastly different trade volumes. The selection of ports included in this analysis is based on economic significance. That is, only ports of entry with an annual import volume of over \$100 million and simultaneous annual export volume of over \$50 million in 2014 have been included in the sample. This restricts the sample to the forty-three largest exporting and importing container ports of entry in the US. Over the sample period, these ports account for roughly 98.70% and 97.75% of total US container imports and exports, respectively.

The extensive trade data are complemented by US and international total employment observations. Monthly data on total non-farm employment by US state have been procured from the *U.S. Bureau of Labor Statistics.* International employment data for OPEC and APEC countries have been obtained from the *International Labour Organization* (ILO).[36] These employment data are used as proxies for importer and exporter income. Although Gross Domestic Product (GDP) at the national level is the common proxy for economic mass in the gravity

[35]The selection of US trade with OECD and APEC countries rests on the data availability concerning economic mass control variables at monthly frequency. Even among these OECD and APEC countries, the unavailability of macroeconomic data leads to the exclusion of several members including Brunei Darussalam, Chinese Taipei, Estonia, Israel, Papua New Guinea, and Slovenia. In addition to these sample restrictions, Austria, the Czech Republic, Hungary, Luxembourg, Slovakia and Switzerland are excluded from the sample because of an unclear treatment or control group status. All of these countries are landlocked and located in Europe. It is unclear whether US trade with these countries is subject to the low sulfur fuel requirement, as these international transactions may be facilitated by non-EU ports. Canada and Mexico are excluded from estimation sample because the liner shipping industry serving the associated transport markets faces a unique market structure, where carriers compete with external transportation options, such as rail or trucking, that are unavailable for alternative bilateral US trade relations. Generally, the inclusion of the later two groups of countries does not alter the primary empirical findings or their statistical significance. The specific results are reported in Panels 2 and 3 of Table 9 in Appendix III.

[36]ILO statistics vary in frequency and are a compilation of employment time series from various national sources. The ILO sources of data used in this analysis include the *EU Labour Force Survey*, the *Labour Force Survey*, the *Population survey on employment problems*, the *General Household Survey*, *National Labour Force Survey*, the *Economically active Population Survey*, the *Household Labour Force Survey*, the *Nueva Encuesta Nacional de Empleo*, the *Encuesta Nacional de Ocupación y Empleo*, the *Encuesta Especializada de Niveles de Empleo*, and *Official Estimates*.

literature, monthly observations of these data are unavailable for the majority of countries included in the sample. Due to this unavailability, highly correlated employment statistics at the foreign country and US state-level are used to control for economic mass variation instead. The application of state-level, rather than national, US employment data controls for local income variations that may vary from national trends and potentially influence the local port-of-entry trade flows.[37]

As indicated in the previous section, the additional control variables include US free trade agreements and monthly observations on regional US diesel fuel prices. The diesel fuel price data have been obtained from the *Energy Information Administration* (EIA). These prices are intended to control for the time variation in costs of heavy fuel oil (HFO) and low sulfur fuels that may change access costs, aside from the EU directive.[38] Data on US free trade agreements, enacted during the 2003-2015 sample period considered in this study, were obtained from the *Office of the United States Trade Representative* (USTR) and involve the sample countries of Australia, Chile, Peru, Singapore and South Korea. The dummy variables indicating these free trade agreements are intended to control for trade liberalization efforts that result in the time variation of US *ad valorem* trade costs, such as tariffs or quotas. The inclusion of the diesel fuel prices and data on free trade agreements completes the unique data set employed in this study.

To summarize and provide a description of these data, as well as justification for the appropriateness of the difference-in-differences estimator, I consider various dimensions of the data. In Table 2, I summarize the US trade data along the cross-sectional dimension and provide summary trade statistics for each of the EU member and non-member countries included in the sample. The summary statistics reveal that US containerized trade varies by the direction of trade (exports vs. imports), across countries, and treatment and control groups. While some

[37]As part of the robustness analysis, I test whether the empirical findings are sensitive to the exclusion of state-level US employment. The results, presented in Panel 2 of Table 10 in Appendix III, demonstrate that the evidenced variation in policy-induced trade effects is robust against the exclusion of state-level US employment.

[38]Due to the limited price data availability of HFO used in the container shipping industry, the No. 2 distillate retail sales prices by refiners are included in the dataset. According to the EIA, residual fuel oils may contain No. 2 distillate in order to meet specifications [Wallace, n.d.] and thus, warrants its use as a proxy for HFO and low sulfur fuel prices.

countries, like China or Japan, hold considerable shares of total US containerized imports, the majority of countries command shares of less than 1%. Similarly, the US container export market exhibits few countries with large market shares, such as China, Japan, or South Korea, and many countries holding export shares around 1%. However, the US container export market appears to be less concentrated, with market shares ranging from 0.03% to 13.02%, than the US container import market, with shares ranging from 0.02% to 38.97%. Despite these differences, there are also some commonalities between exports and imports and between the treatment and control groups. In fact, for both exports and imports, the ten largest US trade partners (measured in average trade value) command over 50% market share, respectively, are comprised of both EU member and non-member countries and share five common members including China, Japan, Germany, South Korea, and Taiwan.

A more detailed comparison between the sample EU member and non-member countries reveals that, with the exception of the largest US trade partners, including China and Japan, the treatment and control groups are very similar concerning average trade values. Specific to this sample, EU member countries hold 16.59% and 21.73% market share of US containerized imports and exports, respectively, while non-member countries excluding China and Japan account for 19.96% and 27.42% of these markets (68.42% and 49.00% including China and Japan).[39] These observations illustrate the importance of controlling for systematic differences in trade values between the treatment and control groups, as well as individual countries and support the use of a DID estimator which accounts for these level differences that would otherwise bias the treatment effect estimation.

Another interesting feature of the data concerns the share of backhaul transport markets for US containerized exports and imports by foreign country. Recall, that a transport market is defined as a backhaul when current bilateral trade flows facilitated in this market are less than the current bilateral trade flows facilitated in the transport market of opposite direction.[40]

[39]Since Japan and, in particular, China hold such market dominant positions concerning US bilateral trade, I re-estimate the empirical model excluding both of these countries. The empirical results are given in Panel 4 of Table 9 in Appendix III and illustrate that estimated trade effects and their statistical significance are largely insensitive to the exclusion of these two countries.

[40]Average shipment durations between the US and Asia or Europe can range from 8 to approximately

Table 2: Avg. US Container Trade Values by Foreign Country

	Imports			Exports		
Country	Trade Value (in $Mil.) (1)	Trade Share (%) (2)	Share of Backhauls (%) (3)	Trade Value (in $Mil.) (4)	Trade Share (%) (5)	Share of Backhauls (%) (6)
EU Members						
Germany	2,520	5.44	19.6	612	3.76	80.4
Italy	1,230	2.66	16.78	252	1.55	83.22
France	960	2.07	24.81	293	1.8	75.19
United Kingdom	895	1.93	41.41	666	4.1	58.59
Netherlands	465	1	61.02	580	3.57	38.98
Spain	368	0.8	34.95	167	1.03	65.05
Ireland	331	0.72	35.57	65	0.4	64.43
Sweden	275	0.59	25.71	82	0.51	74.29
Belgium	246	0.53	70.35	662	4.07	29.65
Denmark	146	0.32	29.22	44	0.27	70.78
Finland	122	0.26	34.4	70	0.43	65.6
Poland	119	0.26	29.09	55	0.34	70.91
Portugal	86	0.18	20.54	16	0.1	79.46
Greece	39	0.08	41.15	24	0.15	58.82
Total	7,680	16.59	-	3,530	21.73	-
Non-Members						
China	18,000	38.97	11.62	2,120	13.02	88.38
Japan	4,390	9.49	24.09	1,390	8.56	75.91
Korea, South	1,560	3.37	32.62	821	5.05	67.38
Taiwan	1,500	3.24	18.74	535	3.29	81.26
Thailand	994	2.15	16.76	203	1.25	83.24
Vietnam	962	2.08	10.6	129	0.8	89.4
Indonesia	926	2	13.43	197	1.21	86.57
Malaysia	672	1.45	14.27	143	0.88	85.73
Australia	383	0.83	56.76	598	3.68	43.24
Philippines	356	0.77	28.94	128	0.79	71.06
Chile	298	0.64	40.52	217	1.34	59.48
Russia	254	0.55	60.33	205	1.26	39.67
Hong Kong	244	0.53	67.66	422	2.6	32.34
Singapore	241	0.52	64.45	364	2.24	35.55
Turkey	236	0.51	35.37	182	1.12	64.63
New Zealand	204	0.44	41.24	73	0.45	58.76
Peru	180	0.39	37.72	140	0.86	62.28
Norway	105	0.23	36.74	39	0.24	63.26
Iceland	9	0.02	53.6	5	0.03	46.4
Total	31,700	68.42	-	7,960	49.00	-

Sources: *USA Trade Online*

The country-specific backhaul share data are presented in columns (3) and (6) of Table 2 and demonstrate that while the share of backhaul transport markets exhibits large heterogeneity across countries, it systematically varies across US exports and imports.[41] In particular, as columns (3) and (6) illustrate, US containerized exports tend to be facilitated in backhaul transport markets, while US containerized imports typically represent a fronthaul transport market. That is, on a round trip facilitating bilateral trade between the US and an OECD or APEC country, the majority of US containerized imports from these countries reflect a fronthaul market for international carriers, while the majority of US containerized exports to these countries reflect a backhaul market for these carriers.

In fact, given this sample, only 28.7% of the total US containerized imports from EU member countries and 17.8% from non-member countries are facilitated in backhaul transport markets. In contrast, over 58% of the total sample US containerized exports to EU member countries and 70.7% of the total sample US exports to non-member countries are facilitated in backhaul transport markets. This shows that there is no inherent difference between the backhaul shares of treatment and control groups, but systematic variation across US containerized imports and exports. Since bilateral US trade tends to be imbalanced, the theoretical findings suggests that maritime transport policy applied to both US containerized imports and exports should, in fact, produce very different responses in US trade regardless of whether carrier joint or access costs are affected.

To further ensure the appropriateness of the DID estimator, the time dimension of the data is considered next. In line with the theoretical and empirical model, I differentiate the

30 days depending on the port of origin and destination. To address the possible one month lag between the fronthaul and backhaul route on a given round trip between the US and an Asian or European country, I perform several robustness checks where the backhaul transport market is defined by comparing this month's US imports(exports) to last month's US exports(imports) for the same US port-foreign country pair. Estimations based on these redefined fronthaul and backhaul routes yields consistent and statistically significant average treatment effects that are presented in Table 11 of Appendix III.

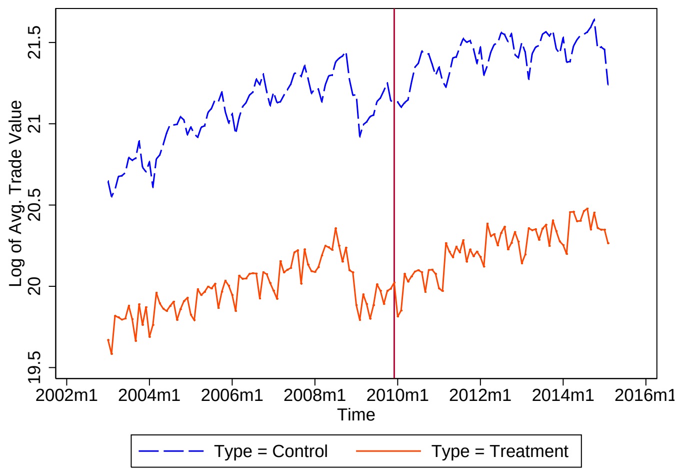
[41]While the primary estimates rely on the backhaul identification at the US port-foreign country level, actual shipping routes may include several stops at a few major US ports and foreign countries. The existence of these primary transatlantic and transpacific shipping routes may alter the fronthaul and backhaul definitions assigned to each US port-foreign country observation. In an attempt to match these shipment patterns and address potential concerns, I aggregate the bilateral US port trade data at state, supranational, as well as state-supranational levels and re-estimate the empirical model. The results reflect point estimates of similar magnitude and statistical significance and are presented in Panels 2 through 4 of Table 12 in Appendix III.

data between treatment and control groups, as well as the fronthaul and backhaul transport markets, rather than between the traditional export and import perspectives. Figures 3.1 and 3.2 illustrate the time path of logged US containerized trade facilitated in fronthaul and backhaul transport markets comparing the trends involving US trade with EU member and non-member countries over the entire sample period. Both figures present supporting evidence of the initial observations from Table 2. That is, US containerized trade facilitated in fronthaul and backhaul transport markets is much larger for non-EU member countries, than EU members. Despite these stark differences in the levels of trade, Figures 3.1 and 3.2 suggest that both fronthaul and backhaul trade exhibit very similar long-run growth patterns across treatment and control groups. This provides supporting evidence for the validity of the parallel paths assumption required by the standard DID estimator.

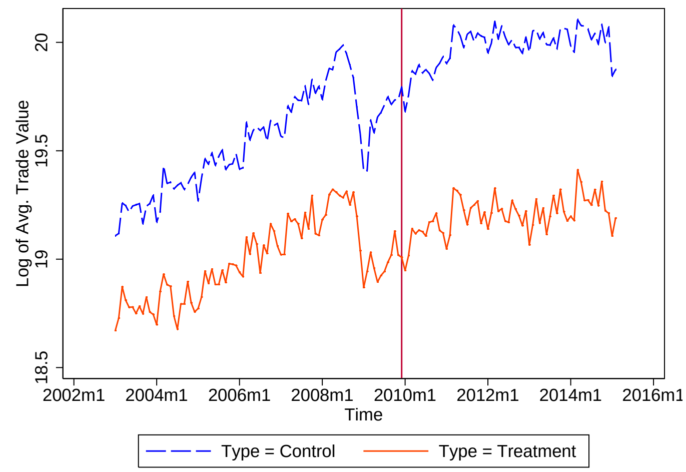
Treatment is indicated via the vertical line. However, due to large short-run variations, Figures 3.1 and 3.2 provide no immediate insight concerning the potential treatment effects. To alleviate this issue, Figures 3.3 and 3.4 present the same data, but restrict the sample period around the treatment date of January 1st, 2010, when the EU low sulfur fuel requirement went into effect. Based on Figures 3.3 and 3.4, it appears that fronthaul and backhaul US trade with either the treatment or control group declines around the treatment date. However, Figures 3.3 and 3.4 also indicate that the magnitude of these declines is larger for the treatment than the control group and varies across fronthaul and backhaul transport markets. The use of the DID estimator should delineate the specific responses of US trade from seasonal and otherwise noisy variation and provide clear quantitative insights into the potentially heterogeneity of trade policy outcomes across fronthaul and backhaul transport markets.

7 Results

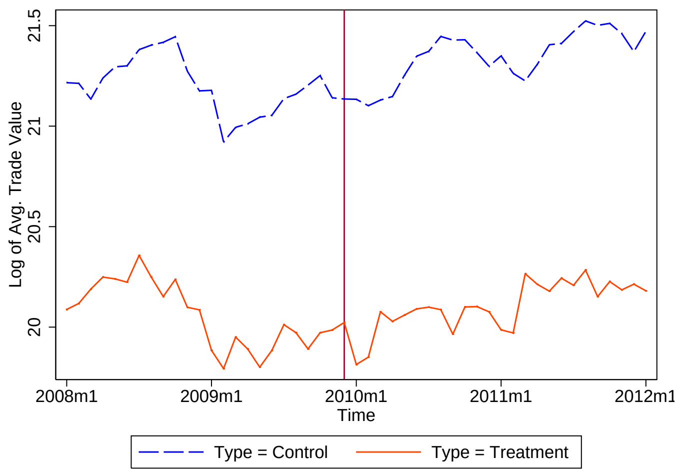
In this section, I first present the empirical findings obtained from the gravity equation estimations of bilateral US containerized trade with OECD and APEC countries. An extension of the analysis further differentiates trade effects across the balanced and imbalanced bilateral trade



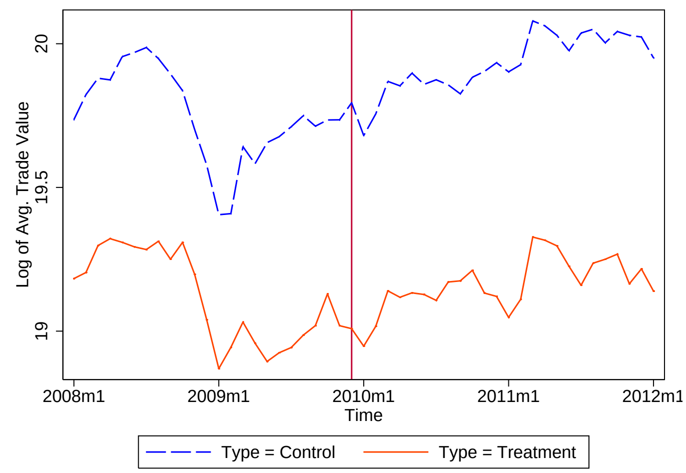
3.1: Fronthaul



3.2: Backhaul



3.3: Fronthaul



3.4: Backhaul

Figure 3: Avg. US Trade Flows across Treatment & Control Groups by Transport Market

samples as well as different product groups. I conclude the analysis with a series of robustness checks and a discussion of its implications. For the majority of these estimations, I use the more recently developed Poisson pseudo-maximum likelihood (PPML) estimator, as suggested by Santos Silva and Tenreyro [2006]. The primary results point to systematic variation in trade policy outcomes across fronthaul and backhaul transport markets and demonstrate that this variation can explain the otherwise surprising difference in trade effects across US exports and imports. The findings of the extended analysis further complement the theoretical predictions. While the differentiation across various trade imbalances illustrates that the difference in fronthaul and backhaul treatment effects decreases as trade becomes more balanced, the disaggregated analysis reveals that trade in high *ad valorem* transport cost products is more responsive to a shock in carrier costs than trade in low *ad valorem* transport cost products. Solidifying the primary empirical findings, I present and discuss the results of various robustness checks involving standard sensitivity analyses, multiple model modifications and various backhaul identifications, among others. In general, this secondary analysis points to the consistency of the empirical results demonstrating systematic heterogeneity of trade policy outcomes across fronthaul and backhaul transport markets. Concluding this section, I emphasize the significance of these findings presenting current aggregated trade imbalance data and deducing the suggested implications across developing versus developed countries and geographic regions. Overall, these data suggest that the transport-related trade effects are consistently larger for low rather than high income countries, but vary dynamically across geographic regions.

7.1 Primary Results

The empirical results for the gravity equation estimation using the PPML estimator are presented in Table 3. Estimation differentiates potentially varying policy effects between the full sample including US containerized exports and imports, as well as each of these trade categories separately. The full sample estimation results, given in column (1) of Table 3, reveal a negative, yet statistically insignificant, effect of the low sulfur fuel requirement on bilateral US-EU trade, relative to all other bilateral US containerized trade with OECD and APEC countries. This finding, however, is without distinction between US exports and imports. Differentiation between the two, presented in columns (2) and (3) of Table 3, unmasks a small and statistically insignificant effect on US containerized imports, but large and statistically significant export treatment effect. That is, US containerized imports from EU countries experience no statistically significant reduction in response to the implementation of EU Directive 2005/32/EC, while US containerized exports to EU members decrease by 7.99%$[\approx (exp(-0.0833) - 1) * 100]$ post treatment; an estimate that is both economically and statistically significant. Without further consideration of the transport sector this finding is surprising. The low sulfur fuel requirement applies to all container vessels at berth in an EU port. Since container vessels are subject to this increase in costs while unloading US exports as well as loading US imports, one would expect both US-EU exports and imports to be negatively affected by the EU Directive.

However, as the theoretical model shows, carriers allocate costs according to fronthaul and backhaul transport markets, rather than import-export specific routes. Furthermore, the model predicts that, in imbalanced trade cases, increases in marginal access costs affect trade in backhaul transport markets more than in fronthaul markets. Since US exports and imports are generally imbalanced and US exports are mainly facilitated in backhaul transport markets, this finding suggests that US exports should experience a larger decline in response to the low sulfur fuel requirement compared to US imports, which are mainly facilitated in fronthaul transport markets. To test this hypothesis, I re-estimate the model differentiating between fronthaul and backhaul transport markets, rather than US imports and exports. The results are given in columns (4) and (5) of Table 3 and provide supporting evidence for *Proposition 1*. Specifically, the treatment effect estimates show that, albeit a negative coefficient point estimate, there is no statistically significant impact on fronthaul transport markets. In contrast, backhaul US-EU trade experiences a statistically significant 9.87% reduction in response to the EU environmental policy relative to all other US containerized backhaul trade with other OECD and APEC countries.

There are a few questions that may arise naturally. One concern may be the overall magnitude of the estimated trade effects. Statistical as well as anecdotal evidence suggests that compliance with the low sulfur fuel regulation requires carriers to use high quality in-port fuels that command an approximate 100% premium and results in an estimated $1.3 billion increase in annual fuel costs [see, for example, (EMSA), 2010, Ivanov, 2010, Notteboom et al., 2010]. Furthermore, Notteboom et al. [2010] have estimated that a similar rise in fuel costs due to European Emission Control Areas will lead to freight rate increases ranging from 8% to 40% for traditional and fast short sea services, respectively. Based on this evidence, significant increases in transport costs and the resulting estimated trade effects appear reasonable. Another concern

Table 3: Average Treatment Effects - PPML

VARIABLES	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Average Treatment Effect, (δ)	-0.030	-0.010	-0.083**	-0.029	-0.104**
	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Observations	410,134	205,067	205,067	205,067	205,067
R-squared	0.896	0.918	0.679	0.903	0.764
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

that may arise, pertains to the difference in magnitudes of the statistically significant treatment effects on US exports to EU countries compared to US-EU trade facilitated in backhaul transport markets. A priori, one might expect the treatment effect on backhaul transport markets to be equal to the effect on US exports. However, as the summary statistics in Table 2 reveal, not all US containerized exports are transported in backhaul markets. Since fronthaul markets show no statistically significant effect, the overall reduction of US exports, which represents a partial blend of the fronthaul and backhaul treatment effects, is, in fact, expected to be smaller than that exhibited by trade in backhaul transport markets. Overall, the estimates provide consistent empirical evidence in support of *Proposition 1*, which states that trade effects are larger in backhaul relative to fronthaul transport markets when marginal access costs are affected.

Another potential source for the heterogeneity of commercial policy outcomes concerns the differences in trade effects across balanced and imbalanced bilateral equilibrium trade flows. The theoretical model predicts that the difference in fronthaul and backhaul average treatment effects in response to an identical shock to marginal access costs should decrease as more balanced bilateral trade observations are considered. To test this hypothesis, I restrict the sample to rather balanced bilateral trade cases and compare the estimated fronthaul and backhaul trade effects.[42] Columns (1) and (2) of Table 4 present the average fronthaul and backhaul

[42] Perfectly balanced trade observations are rare and treatment effects cannot be identified in this case.

Table 4: Average Treatment Effects - Varying Trade imbalance

	(1) Fronthaul $\eta > 0.5$	(2) Backhaul $\eta > 0.5$	(3) Fronthaul $\eta > 0.8$	(4) Backhaul $\eta > 0.8$
Panel 1 - Full sample	-0.059	-0.080	-0.026	-0.036
Average Treatment Effect, (δ)	(0.085)	(0.091)	(0.116)	(0.119)
Panel 2 - Drop zero-valued balanced trade	-0.068	-0.091	-0.061	-0.072
Average Treatment Effect, (δ)	(0.085)	(0.091)	(0.118)	(0.120)
Port FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

treatment effects restricting the sample to observations where the value of backhaul US trade is at least half of the value of fronthaul US trade ($\eta = min(x_{ijpt}/x_{jipt})/max(x_{ijpt}, x_{jipt}) > 0.5$). In contrast, Columns (3) and (4) of Table 4 illustrate the results of identical estimations that restrict the sample to even more balanced bilateral trade observations where the difference between fronthaul and backhaul trade is no larger than 20% ($\eta > 0.8$). While Panel 1 considers all balanced bilateral trade flows, including zero-valued trade, Panel 2 presents the results of identical estimations, but limiting the sample non-zero valued trade observations.

In contrast to the previous results, restricting the sample to rather balanced bilateral trade observations yields statistically insignificant treatment effects in both fronthaul and backhaul transport markets. However, the point estimates of the individual treatment effects, presented in columns (1)-(4) of Table 4, suggest nearly identical fronthaul and backhaul policy outcomes when trade is rather balanced. This finding nicely contrasts the drastic variation in estimated fronthaul and backhaul trade effects when rather imbalanced trade observations are included as well. In fact, comparing the coefficient estimates across fronthaul and backhaul transport markets when zero-valued balanced trade is excluded, displayed in Panel 2 of Table 4, it can be shown that the trade effects in the respective transport markets vary by only 25%($\eta > 0.5$) to 15%($\eta > 0.8$) depending on the sample restriction. Importantly, these results indicate that the variations in policy outcomes further decrease as trade becomes more balanced. While these findings provide suggestive evidence in support of the theoretical predictions, they lack the statistical significance.

To strengthen this empirical evidence, I relax the previous sample restrictions and consider the variation in trade effects across all levels of bilateral trade imbalances via the estimation of marginal effects. These marginal treatment effects are derived from an ordinary least squares estimation including the interaction of the treatment indicator with a measure of bilateral US trade imbalances. Figure 4 displays the fronthaul and backhaul marginal trade effects, along with the respective 90% confidence intervals, of the low sulfur fuel requirement. The graphs are consistent with the previous results and reveal negative marginal backhaul trade effects that become statically significant at the 10% level when the difference between fronthaul and backhaul trade is no larger than 70%(=1-Trade Balance). In contrast, the estimated marginal fronthaul treatment effects are largely insignificant at any conventional level of significance. More importantly, the graphs illustrate that the point estimates of marginal fronthaul and backhaul trade effects are converging as bilateral trade becomes more balanced and are nearly indistinguishable at a trade balance of 90% to 100%. These findings further substantiate the theoretical results.

7.2 Product Level Results

In addition to the results obtained from the aggregate data analysis, evidence of heterogeneous policy outcomes at the product level may be of considerable interest to policy-makers as well. To give insight into the theoretically suggested variation of trade policy outcomes across various product groups, I re-estimate the empirical model using disaggregated data that combines two digit HS code level products[43] according to their average *ad valorem* transport costs.[44] Dividing the data into product groups with above and below average *ad valorem* transport cost yields

[43] These codes coincide with the product category levels as defined in the *Harmonized Tariff Schedule* (HTS) that is administered by the U.S. International Trade Commission, (USITC).

[44] In the given context, *ad valorem* transport costs can be thought of as the ratio of transport cost relative to associated container values in terms of percentages.

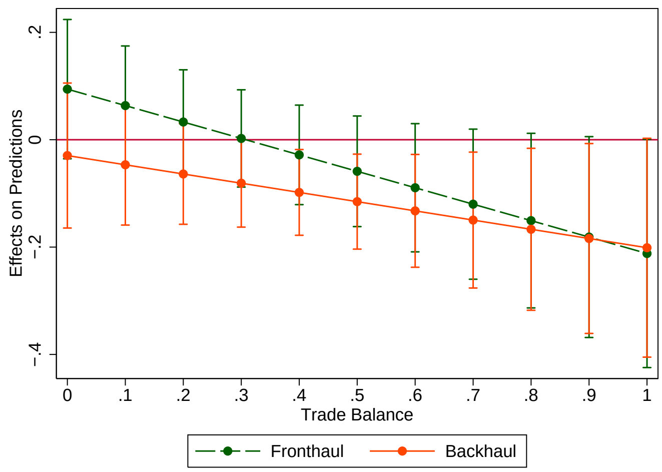


Figure 4: Marginal Treatment Effects by Transport Market and Trade Imbalance

empirical results that support the initial findings at the aggregate level. That is, the low sulfur fuel requirement is a larger deterrent to US-EU trade facilitated in backhaul rather than fronthaul transport markets. More importantly however, the analysis provides novel evidence in support of *Proposition 2* showing that the trade effects from maritime transport policy are, indeed, increasing in *ad valorem* transport costs.

Recent research by the working party of the OECD Trade Committee has shown that *ad valorem* transport costs exhibit large variation at the product group level and averaged 6.7% for the top twenty product groups of US imports from China, for example [Korinek, 2011]. In fact, the author reveals that *ad valorem* transport costs range from 3.7% to 15.7% for the most traded product groups, but also points out that some specific goods are subject to much higher rates. Variation in these *ad valorem* transport costs across products stems not only from differences in the unit value of each product, but also from differences in container capacity utilization. Meaning, bulky products, such as assembled furniture, or heavy goods, like wood and metal for example, cannot take advantage of the low cost transport capacity provided by containers and thus, hold a low per-container value. In contrast, light products, such as clothing or footwear, or high value added products, such as electrical or mechanical machinery for example, can achieve higher per-container values and thus, lower *ad valorem* transport costs by maximizing container capacity utilization.

For the given analysis in this study, trade is disaggregated into two product groups with either high or low *ad valorem* transport costs where the threshold is set at 6.7%, the average of the *ad valorem* transport cost data presented by Korinek [2011].[45] Categorization also follows Korinek [2011] and is therefore, limited to twenty-five product groups.[46] The theoretical hypothesis to be tested is summarized in *Proposition 2* and states that an identical shock to carrier costs is expected to have a larger effect on products with high *ad valorem* transport costs compared to those with low *ad valorem* transport costs.

The primary PPML estimation results of the disaggregated analysis are presented in Table 5 and display the differentiated average treatment effects of the low sulfur fuel requirement on the low and high *ad valorem* transport cost product groups, respectively. In general, the estimated trade effects for low *ad valorem* transport cost products, with the exception of US imports from EU members, are small and statistically insignificant. In contrast, with the exception of US exports to EU members, the EU Directive has large, negative, and statistically significantly different treatment effects on all US-EU trade in products with high *ad valorem* transport costs. Intuitively, this implies that equal increases in freight rates due to the low sulfur fuel requirement are, in fact, more taxing on bulky and heavy products that have lower total container values, than small or high value added products that command relatively high total container values.

Moreover, the disaggregated estimates reveal that fronthaul US-EU trade of high *ad valorem* transport cost products experiences a statistically significant decline of 7.72%. This provides additional evidence that the low sulfur fuel requirement did, in fact, raise marginal access costs for both US exports and imports to and from EU members and has led to a decline in US-EU trade facilitated in both fronthaul and backhaul transport markets. A comparison of

[45]The robustness of the results to variations in this threshold ranging from 6% to 8% has been evaluated and, in general, the disaggregated results are consistent across these variations.

[46]Product groups with high *ad valorem* transport costs exceeding 6.7% include *Plastics* (39), *Rubber* (40), *Wood* (44), *Paper and related articles* (47-49), *Ceramic products* (69), *Iron and Steel* (72-73), *Miscellaneous articles of base metal* (83), *Vehicles* (87) and *Furniture* (94), whereas product groups with *ad valorem* transport costs below 6.7% include *Organic chemicals* (29), *Articles of leather, etc.* (41-42), *Knitted clothing* (61), *Non-knitted clothing* (62), *Other textile articles* (63), *Footwear* (64), *Tools* (82), *Mechanical machinery* (84), *Electrical machinery* (85), *Photo/Cinema equipment* (90) and *Toys* (95).

Table 5: Average Treatment Effects at the Disaggregated Product Group Level

VARIABLES	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Average Treatment Effect, (δ)	0.047	0.098*	-0.061	0.049	-0.013
(low *ad valorem* transport costs)	(0.045)	(0.052)	(0.052)	(0.052)	(0.059)
Differential Average Treatment Effect	-0.122***	-0.136**	-0.073	-0.129**	-0.185***
(high *ad valorem* transport costs)	(0.045)	(0.060)	(0.061)	(0.055)	(0.063)
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

the fronthaul and backhaul high *ad valorem* transport cost product treatment effects, given in columns (4) and (5) of Table 5, illustrates that US-EU trade of these products experienced a larger decline in backhaul transport markets. In fact, the point estimates of column (5) show that backhaul US-EU trade declined by 17.93% in response to the EU Directive relative to the previously indicated 7.72% decline of fronthaul US-EU trade. This finding provides additional evidence in support of *Proposition 1* that trade facilitated in fronthaul markets exhibits a smaller elasticity with respect to marginal access costs than trade facilitated in backhaul transport markets. [47] In summary, all of these empirical findings compliment the theoretical results that the elasticity of trade with respect to marginal access costs is, indeed, increasing in *ad valorem* transport costs, heterogeneous across fronthaul and backhaul transport markets and displaying vanishing transport market differences for rather balanced bilateral trade observations.

[47] All of these results are largely insensitive to variations concerning the dividing threshold. That is, empirical findings obtained when the data are restricted to products with the highest and lowest 25% *ad valorem* transport costs are qualitatively similar to those presented in Table 5.

7.3 Robustness Analyses

To test the consistency of the primary empirical findings presented above, a multitude of robustness checks have been performed. These analyses include alterations in the DID specification, variations in standard error clustering, alternative fixed effects specifications, variations in sample restrictions, changes in the empirical model specification and alterations concerning the backhaul identification. The respective results are reported in Tables 6-12 of Appendix III.[48]

DID Specifications

At a fundamental level, the first robustness check tests the appropriateness of the DID estimator. Panels 2 and 3 of Table 6 present the results obtained from the inclusion of treatment and control group as well as country-specific time trends, respectively. The inclusion of these time trends in the estimation tests the appropriateness of the parallel paths assumption. The obtained results are consistent across the various trend specifications and support the use of the DID estimator.

Clustering

Through the second robustness analysis, I scrutinize the statistical significance of the primary empirical results re-estimating the model using various levels of clustered standard errors. While the statistical significance of the primary results is based on standard errors clustered at the the route specific US port-foreign country level, this robustness analysis involves clustered standard errors at the US state-foreign country, US port and US state levels. These changes in the level of cluster aggregation explore potential cluster correlations across ports and foreign trade partners. The respective results are reported in columns 3 through 8 of Table 7 and illustrate that the statistical significance of the primary results is generally robust to these estimation adjustments.

[48]For the ease of comparison, each of these tables first reports the primary empirical findings.

Fixed Effects

Following standard practices in the trade literature, I also test the robustness of the empirical results against the inclusion of alternative sets of fixed effects. Evaluating the importance of time-varying unobservable trade costs at a more local level, I incrementally include time-varying fixed effects at the US region, state and port level. The respective results are reported in columns 3 through 8 of Table 8 and point to relatively stable coefficient estimates and statistical significance in fronthaul and backhaul transport markets.

Sample Restrictions

While alternative fixed effects and cluster specifications are common practice in a variety of empirical applications, the following robustness checks are rather specific to this study. In Panels 2 through 4 of Table 9, I report the estimation results obtained from various alterations of the sample restrictions. In particular, I test whether the inclusions of landlocked European countries as well as the North American US trade partners, Canada and Mexico, or exclusion of market dominant foreign countries, such as China and Japan, alter the primary finding of heterogeneous trade policy outcomes. The corresponding results illustrate that none of these exclusions drive the primary empirical findings and ease the concerns of potential sample selection bias.

Model Alterations

In addition to these sample restrictions, I also investigate the sensitivity of the empirical results to alterations of the empirical model specification and aggregation of the data to quarterly rather than monthly frequency. Panels 2 and 3 of Table 10 report the empirical findings obtained from estimations excluding US state level employment as well as US free trade agreements, respectively. The results indicate that the estimated treatment effects and their statistical significance are not reliant on the inclusion of these control variables. In panel 4 of Table 10, I present the results obtained from the inclusion of six month lagged explanatory variables. Once again, the coefficient estimates and their statistical significance are robust and do not depend on the inclusion of these lagged control variables.

Contrary to these model alterations, Panel 5 of Table 10 provides the estimation results based on aggregated data at quarterly, rather than monthly frequency. This aggregation is used to evaluate the potential issues arising from the *lumpiness of trade* [see, for example, Hornok et al., 2011] that may obscure the precise estimation of average treatment effects. The reported results for the quarterly aggregated data demonstrate that the negative average treatment effects of the low sulfur fuel requirement vary by only a small margin compared to primary results based on monthly data and continue to be statistically significant at a 5% level for estimations involving US exports and US trade facilitated in backhaul transport markets.

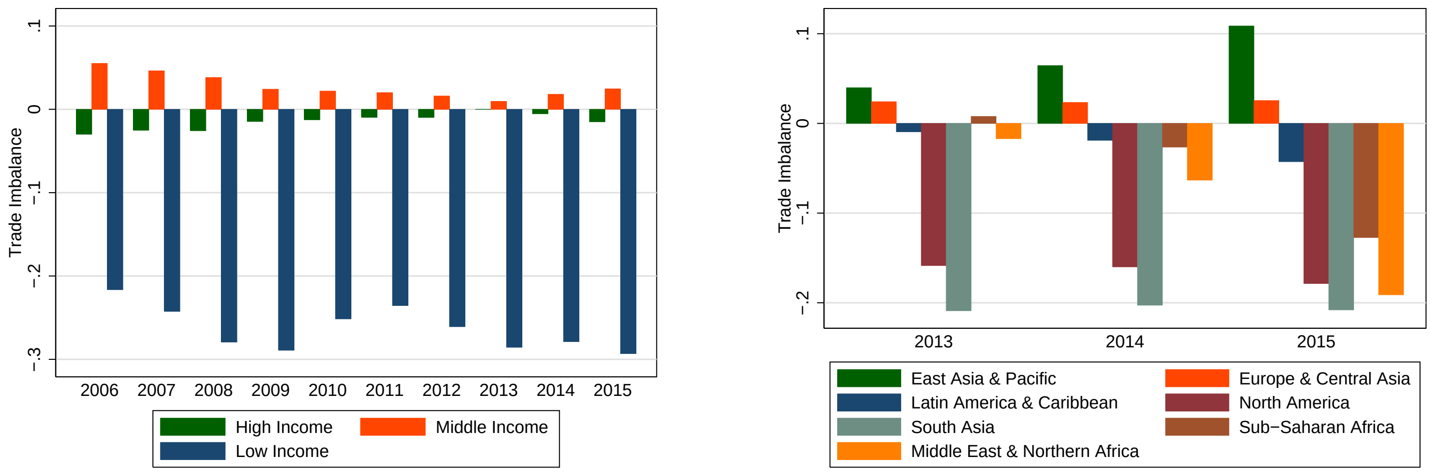
Backhaul Identification

Lastly, I explore whether the empirical results are consistent across various changes to the identification of fronthaul and backhaul transport markets. These changes are intended to capture alternative transportation patterns of bilateral US trade and are performed along the time and cross-sectional dimensions of the data. Given the fact that transatlantic as well as transpacific shipping between the US and Asian as well as European countries can take anywhere from eight to over thirty days depending on the port of origin and destination, the original identification of backhaul markets based on current month bilateral trade comparisons may be distorted. To address this concern, I redefine a backhaul transport market comparing current month's US imports(exports) with last month's US exports(imports) for the same US port-foreign country pair. Estimation based on these redefined fronthaul and backhaul transport patterns yields robust results both in terms of the magnitude and statistical significance of the estimated average treatment effects and are reported in Table 11.

In addition to these variations in shipment durations, it is possible that actual transatlantic and transpacific shipping routes are more complex than the simple US port-foreign country trade observations available in the data used for this study. General shipping patterns, in fact, suggest that most of the bilateral US trade considered in this study is handled by only a few major ports located in the US and other foreign countries in Asia and Europe. Of course, this added layer of complexity may mask the actual fronthaul and backhaul shipment structure. To capture the potential changes in fronthaul/backhaul patterns created by these multi-stop shipping routes, I aggregate the data at the international supranational, US state-supranational and US region-supranational levels and re-estimate the model. In general, the results presented in Panels 2 through 4 of Table 12 reflect point estimates of similar magnitude relative to the primary results given in Panel 1. While the statistical significance of these estimates varies for US exports, backhaul transport markets continue to reflect a trade reduction that is statistically significant at either the 10% or 5% level. Interestingly, the potentially most realistic representation of actual shipping routes, aggregating the data at the US region-supranational level, given in Panel 4, shows statistically significant trade reductions for overall trade and fronthaul transport markets, in addition to the consistently significant estimates for exports and backhaul transport markets.

7.4 Implications

In summary, the empirical analyses conducted in this study provide novel and consistent evidence in support of the theoretically suggested heterogeneity in trade policy outcomes. While all of the aggregate findings provide evidence in favor of *Proposition 1*, the results based on disaggregated product level data substantiate the theoretical hypothesis manifested in *Proposition 2*. That is, when trade is imbalanced, trade policy reducing marginal access costs exhibits treatment effects that are larger in backhaul relative to fronthaul transport markets and increasing in *ad valorem* transport costs. Overall, these findings accentuate the relevance of the international transport sector to the determination of trade and point to potentially large differences in policy outcomes pertaining to US containerized trade. That is, commercial policy, such as infrastructure investments or deregulation of customs directives that lead to lower marginal access costs, may be much more effective for US containerized exports than imports, which are mainly facilitated in backhaul, rather than fronthaul transport markets.



5.1: Income Level

5.2: Geographic Region

Figure 5: Average Aggregate Trade Imbalance by Income Level and Geographic Region

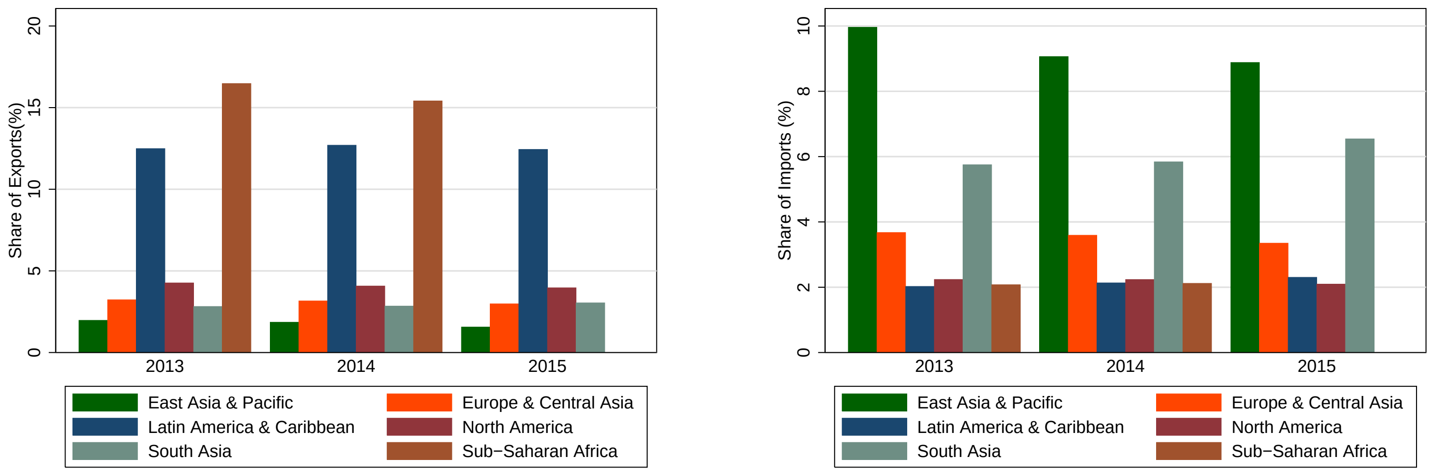
The implications of this study, however, are not only domestic in scope. As the results presented in Tables 3 through 5 as well as Figure 4 suggest, variations in transport-related policy outcomes are closely connected to bilateral trade imbalances and the overall trade composition. Merchandise trade statistics, obtained from the *World Bank Database* and presented in Figures 5.1 and 5.2, reveal that aggregated trade imbalances exhibit large and fairly permanent fluctuations across high to low income countries, yet they exhibit dynamic changes across geographic regions. More specifically, Figure 5.1 shows that trade imbalances experienced by low income countries are significantly and consistently larger than those displayed by middle to high income countries. In conjunction with the empirical result that the difference in trade effects is increasing in the trade imbalance, this observation suggests that low income countries are exposed to much larger export and import volatility considering transport-related policy outcomes compared to middle to high income countries. Moreover, Figure 5.1 shows that low income countries tend to be net importers suggesting that exports of these countries are mainly facilitated in backhaul transport markets. Based on the empirical results, exports of low income countries are therefore subject to disproportionate trade effects from transport-related policies that affect carrier access costs - a conjecture that emphasizes both the potential and risk of transport-related policies in developing countries.

In contrast, Figure 5.2 offers a geographical comparison of aggregated trade imbalances. The data demonstrate stark geographical differences that are subject to considerable short-run fluctuations for some regions. Sub-Saharan Africa, for example, progresses from a slight net exporting region in 2013 to a considerable net importing region by 2015. Given the empirical findings, this observation suggests dynamic variation in transport-related trade effects that add significant complexities concerning the effectiveness of commercial and maritime policies.

Complementing the differences in the patterns of trade, trade composition displays considerable geographic variation as well. As indicated by Figures 6.1 and 6.2, the shares of heavy ore and metal relative to overall merchandise exports and imports are asymmetrically distributed across various global regions. While Sub-Saharan Africa and Latin America as well as the Caribbean display considerable export shares in bulky products, such as ore and metal, South and East Asia as well as the Pacific region command larger import shares of these products. Based on the qualitative and quantitative evidence that high *ad valorem* transport cost products display larger trade effects in response to transport-related policies, this composition of trade suggests disproportionate export volatility for the former regions and disproportionate import fluctuations for the latter. The suggested influence of the patters and composition of trade on policy effectiveness via the channel of international transportation raises a host of research questions with considerable merit for economic development and pertaining to a variety of international policies.

8 Conclusion

In this study, I extend a model of international trade by integrating a transport sector that subsumes the key feature of joint round trip production present in the international container shipping industry and allows for asymmetric and integrated bilateral transport costs to be endogenously determined in equilibrium. Given this theoretical model, I demonstrate that trade policy implications may vary across different types of trade flows and develop two specific propositions about this systematic heterogeneity of trade policy outcomes.



6.1: Export

6.2: Import

Figure 6: Average Export and Import Share of Ore and Metal by Geographic Region

The empirical findings of this study provide supporting evidence for these theoretical hypotheses. Based on the results, I conclude that the low sulfur fuel requirement enacted as part of EU Directive 2005/33/EC raised marginal access costs for both US-EU exports and imports and caused a significant reduction in US-EU containerized trade facilitated in backhaul transport markets; a finding that is consistent across a host of robustness analyses, including trade imbalance variations, data aggregation and various estimation sample restrictions, among others. In contrast, the response of US-EU trade facilitated in fronthaul transport markets has been markedly smaller and becomes statistically significant only when more balanced trade cases or high *ad valorem* transport cost products are considered. Further differentiation of the data reveals that this heterogeneity in treatment effects is decreasing as trade becomes more balanced. In conjunction with aggregate data on the patterns of international trade, these findings suggests that the effects of trade policy are rather symmetric for middle to high income countries with nearly balanced trade but rather volatile for low income countries with considerable merchandise trade deficits.

Additional analysis conducted at a more disaggregated product group level suggests that responses to trade or environmental policy, such as the low sulfur fuel requirement, are not only asymmetric across fronthaul and backhaul transport markets, but also idiosyncratic across product groups. The results show that US-EU trade in products subject to higher relative transportation costs, such as plastics, metals, vehicles or furniture, is more responsive to changes in carrier costs than US-EU trade of product groups with comparably low relative transportation costs, such as apparel and footwear, or electrical and mechanical machinery.

Overall, these findings point to the relevance of the international transport sector in the determination of the patterns and composition of trade. The differences concerning the estimated trade effects provide supporting evidence for the theoretically suggested heterogeneity in commercial and related policy outcomes and identify the backhaul problem as the source of this variation. Naturally, these findings have considerable implications for US policy intended to stimulate US exports or imports in general and are of particular importance when specific products or bilateral trade relations are targeted. However, the results also point to the fact that foreign maritime and related policy can have negative externalities for US trade as well. This feature of the analysis demonstrates that commercial policy intended to stimulate US trade, via carrier cost reductions, must not be limited to the domestic and unilateral scope, but could involve international multilateral efforts.

Future research may focus on identifying the varying responses of trade to changes in marginal joint costs or test whether policy outcomes vary for alternative commercial policies, such as preferential trade agreements. These inquiries could further delineate between the effects on individual products or differences in policy implications across developing and developed countries.

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9 Appendix

A.I Proof of Propositions 1 and 2

Proof of Proposition 1:

Consider three countries, i, j, k, with imbalanced bilateral trade, such that transport market ik facilitating trade from country i to country k is considered a fronthaul and transport market ij facilitating trade from country i to country j is considered a backhaul, $Q_{ik} > Q_{ki}$ and $Q_{ij} < Q_{ji}$. Suppose that for these three countries, i, j, k, we have $a_{ij} = a_{ik}$ and $\tau_{ij} = \tau_{ik}$. Given these assumptions and the fact that $JC' > 0$, equation (13) shows that

$$\left| \frac{\partial q_{ij}}{\partial a_{ij}} \frac{a_{ij}}{q_{ij}} \right| = \sigma \frac{a_{ij}}{p_i \tau_{ij} + a_{ij}} > \sigma \frac{a_{ik}}{p_i \tau_{ik} + a_{ik} + JC'} = \left| \frac{\partial q_{ik}}{\partial a_{ik}} \frac{a_{ik}}{q_{ik}} \right|. \tag{17}$$

This provides the proof that when equilibrium trade is imbalanced, trade facilitated in fronthaul transport markets is more inelastic than otherwise identical trade facilitated in backhaul transport markets.

Proof of Proposition 2:

Recall that, in the imbalanced trade case, the elasticity of trade facilitated in backhaul transport markets with respect to marginal access costs is negative, $\left(\frac{\partial q_{ij}}{\partial a_{ij}} \frac{a_{ij}}{q_{ij}} < 0\right)$. In order for imbalanced trade in larger valued products to be less responsive to a shock in marginal access costs than trade of lower valued products, the elasticity of trade facilitated in backhaul transport markets given by equation (13) must be increasing in the domestic sales price, p_i:

$$\frac{\partial \left(\frac{\partial q_{ij}}{\partial a_{ij}} \frac{a_{ij}}{q_{ij}}\right)}{\partial p_i} = \sigma \frac{a_{ij} \tau_{ij}}{\left(p_i \tau_{ij} + a_{ij}\right)^2} > 0. \tag{18}$$

A.II Derivation of Trade Elasticities in the Value Case

The total value of county i's exports to country j, denoted by x_{ij}, is defined as:

$$x_{ij} = p_{ij}q_{ij} = (\tau_{ij}p_i + f_{ij}) \left[\frac{\sigma}{\sigma - 1}(\tau_{ij}p_i + f_{ij})\right]^{-\sigma} = \left(\frac{\sigma}{\sigma - 1}\right)^{-\sigma} [(\tau_{ij}p_i + f_{ij})]^{1-\sigma} \tag{19}$$

Following the theoretical derivations presented in subsection 4.3, I initially consider a shock to marginal access cost. In the balanced bilateral trade case, the elasticity of the value of trade with respect to a change in marginal access costs is given by

$$\frac{\partial x_{ij}}{\partial a_{ij}}\frac{a_{ij}}{x_{ij}} = (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} < 0 \text{ if } Q_{ij} = Q_{ji}, \tag{20}$$

while in the imbalanced trade case, this elasticity can be represented as follows:

$$\frac{\partial x_{ij}}{\partial a_{ij}}\frac{a_{ij}}{x_{ij}} = (1-\sigma)\frac{a_{ij}}{(p_i\tau_{ij} + f_{ij})}\frac{\partial f_{ij}}{\partial a_{ij}} = \begin{cases} (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}+JC'} < 0 & \text{if } Q_{ij} > Q_{ji} \quad (\textit{fronthaul}) \\ (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}} < 0 & \text{if } Q_{ij} < Q_{ji} \quad (\textit{backhaul}) \end{cases} .(21)$$

Next, I consider the effects of a change in marginal joint costs. Again, I differentiate between the balanced and imbalanced trade cases but now consider the effects on the value of trade instead of the volume. In the balanced case, I obtain the following expression for the elasticity of the value of trade with respect to marginal joint costs:

$$\frac{\partial x_{ij}}{\partial JC'}\frac{JC'}{x_{ij}} = (1-\sigma)\frac{JC'}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} \text{ if } Q_{ij} = Q_{ji}, \tag{22}$$

whereas in the imbalanced trade case this elasticity of trade can be represented as:

$$\frac{\partial x_{ij}}{\partial JC'}\frac{JC'}{x_{ij}} = (1-\sigma)\frac{JC'}{(p_i\tau_{ij} + f_{ij})}\frac{\partial f_{ij}}{\partial JC'} = \begin{cases} (1-\sigma)\frac{JC'}{p_i\tau_{ij}+a_{ij}+JC'} & \text{if } Q_{ij} > Q_{ji} \quad \text{(fronthaul)} \\ 0 & \text{if } Q_{ij} < Q_{ji} \quad \text{(backhaul).} \end{cases} \tag{23}$$

A comparison between equation (12) and (20), (13) and (21), (14) and (22), as well as (15) and (23) reveals that the trade elasticities with respect to marginal access as well as joint cost in the volume and value cases are solely distinguished by the scaling factors of $-\sigma$ and $(1-\sigma)$, respectively. It is trivial to show that *Proposition 1* and *Proposition 2* continue to hold when the value rather than the volume of trade is considered.

A.III Robustness Analyses

Table 6: Robustness Analysis - Time Trend Inclusive Specification

VARIABLES	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Panel 1 - Primary Results	-0.030	-0.010	-0.083**	-0.029	-0.104**
Average treatment effect, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Treatment/Control Group Time Trends	-0.045	-0.027	-0.085**	-0.044	-0.109**
Average treatment effect, (δ)	(0.037)	(0.046)	(0.040)	(0.045)	(0.047)
Panel 3 - Country Specific Time Trends	-0.037	0.005	-0.078*	-0.038	-0.111**
Average treatment effect, (δ)	(0.039)	(0.043)	(0.044)	(0.045)	(0.052)
Observations	410,134	205,067	205,067	205,067	205,067
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Robustness Analysis - Varying Levels of Clustered Standard Errors

VARIABLES	(1) Fronthaul	(2) Backhaul	(3) Fronthaul	(4) Backhaul	(5) Fronthaul	(6) Backhaul	(7) Fronthaul	(8) Backhaul
Average Treatment Effect, (δ)	-0.029	-0.104**	-0.029	-0.104*	-0.029	-0.104***	-0.029	-0.104***
	(0.040)	(0.045)	(0.039)	(0.055)	(0.030)	(0.040)	(0.025)	(0.036)
Level of Clustering	Port-Country	Port-Country	State-Country	State-Country	Ports	Ports	State	State
Number of Clusters	1419	1419	726	726	43	43	22	22

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Robustness Analysis - Varying Fixed Effects Specifications

VARIABLES	(1) Fronthaul	(2) Backhaul	(3) Fronthaul	(4) Backhaul	(5) Fronthaul	(6) Backhaul	(7) Fronthaul	(8) Backhaul
Average Treatment Effect, (δ)	-0.029	-0.104**	0.006	-0.080*	-0.021	-0.091**	-0.018	-0.091*
	(0.040)	(0.045)	(0.037)	(0.042)	(0.035)	(0.046)	(0.033)	(0.047)
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Time FE	Yes	Yes	No	No	No	No	No	No
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-Time FE	No	No	Yes	Yes	No	No	No	No
State-Time FE	No	No	No	No	Yes	Yes	No	No
Port-Time FE	No	No	No	No	No	No	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Robustness Analysis - Various Sample Restrictions

	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Panel 1 - Primary Results	-0.030	-0.010	-0.083**	-0.029	-0.104**
Average treatment effect, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Added Landlocked European Countries	-0.020	0.006	-0.088**	-0.018	-0.100**
Average treatment effect, (δ)	(0.032)	(0.039)	(0.040)	(0.038)	(0.045)
Panel 3 - Added North American Countries	-0.022	0.004	-0.092**	-0.019	-0.101**
Average treatment effect, (δ)	(0.032)	(0.039)	(0.039)	(0.038)	(0.045)
Panel 4 - Exclusion of China & Japan	-0.048	-0.031	-0.093*	-0.062	-0.100*
Average Treatment Effect, (δ)	(0.042)	(0.051)	(0.048)	(0.045)	(0.057)
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Robustness Analysis - Alternative Empirical Model Specifications

	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Panel 1 - Primary Results	-0.030	-0.010	-0.083**	-0.029	-0.104**
Average treatment effect, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Exclude US State Employment	-0.025	-0.010	-0.083**	-0.021	-0.092**
Average treatment effect, (δ)	(0.033)	(0.042)	(0.040)	(0.040)	(0.047)
Panel 3 - Exclude US FTAs	-0.031	-0.012	-0.083**	-0.029	-0.111**
Average treatment effect, (δ)	(0.034)	(0.041)	(0.040)	(0.040)	(0.049)
Panel 4 - Include Lagged Control Variables	-0.041	-0.013	-0.086**	-0.029	-0.107**
Average treatment effect, (δ)	(0.034)	(0.043)	(0.039)	(0.043)	(0.046)
Panel 5 - Aggregated Quarterly Data	-0.028	-0.005	-0.091**	-0.022	-0.117**
Average treatment effect, (δ)	(0.034)	(0.042)	(0.040)	(0.042)	(0.049)
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Robustness Analysis - Varying Backhaul Identifications

VARIABLES	(1) Fronthaul - Primary	(2) Backhaul - Primary	(3) Fronthaul - Export Lag	(4) Backhaul - Export Lag	(5) Fronthaul- Import Lag	(6) Backhaul - Import Lag
Average Treatment Effect, (δ)	-0.029	-0.104**	-0.027	-0.114**	-0.040	-0.103**
	(0.040)	(0.045)	(0.041)	(0.047)	(0.039)	(0.047)
Port FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12: Robustness Analysis - Backhaul Identification at Varying Levels of Aggregation

	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
Panel 1 - Primary Results	-0.030	-0.010	-0.083**	-0.029	-0.104**
Average treatment effect, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Supranational Aggregation	-0.054	-0.050	-0.078	-0.053	-0.098*
Average Treatment Effect, (δ)	(0.036)	(0.031)	(0.069)	(0.039)	(0.059)
Panel 3 - US State - Supranational Aggregation	-0.054	-0.050	-0.078	-0.043	-0.105**
Average Treatment Effect, (δ)	(0.033)	(0.032)	(0.048)	(0.036)	(0.045)
Panel 4 - US Region - Supranational Aggregation	-0.045*	-0.050	-0.078***	-0.068*	-0.096**
Average Treatment Effect, (δ)	(0.027)	(0.033)	(0.029)	(0.036)	(0.038)
Port FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Imp-Exp FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1