ESSAYS ON TRADE AND TRANSPORTATION

by

FELIX L. FRIEDT

A DISSERTATION

Presented to the Department of Economics
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

June 2017

DISSERTATION APPROVAL PAGE

Student: Felix L. Friedt

Title: Essays on Trade and Transportation

This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Economics by:

Bruce Blonigen	Co-Chair
Wesley Wilson	Co-Chair
Anca Cristea	Core Member
Jeremy Piger	Core Member
Nagesh Murthy	Institutional Representative

and

Scott L. Pratt	Dean of the Graduate School

Original approval signatures are on file with the University of Oregon Graduate School.

Degree awarded June 2017

DISSERTATION ABSTRACT

Felix L. Friedt

Doctor of Philosophy

Department of Economics

June 2017

Title: Essays on Trade and Transportation

This dissertation considers the interconnections between trade and transportation. Through various theoretical and empirical analyses, I provide novel evidence of the simultaneity of trade and transportation, of spillover effects across integrated transport markets, and of the influence of the international transport sector on trade policy effectiveness and natural disaster induced trade disruptions.

In the first substantive chapter, I develop a model of international trade and transportation. Accounting for the joint-production present in the international container shipping industry, I illustrate that freight rates adjust to differences in the international demands for transport and can result in balanced or imbalanced equilibrium trade in the presence of asymmetric freight rates. The empirical results exhibit the simultaneity of international trade and transportation costs and show that the dependence of transport costs on the trade imbalance can lead to spillover effects across bilateral export and import markets.

In the second substantive chapter, I investigate the effects of maritime trade policy on bilateral trade in the presence of trade imbalances. Using the previously developed model, I show that the trade elasticities with respect to carrier costs vary systematically across transport markets, bilateral trade imbalances and differentiated products. Empirically, I estimate the varying effects of an EU environmental policy on U.S.-EU trade and provide strong evidence in support of the theoretical results.

In the third substantive chapter, I analyze the dynamics and spatial distribution of the trade effects induced by natural disasters. I develop a spatial gravity model of international trade and apply the model to monthly US port level trade data. Empirically, I estimate the dynamic evolution of trade effects caused by Hurricane Katrina differentiating trade disruptions at the local port level. The estimates point to the static and dynamic resilience of international trade. While ports closest to Katrina's epicenter experience significant short-run reductions that can be of permanent nature, international trade handled by nearby ports rises in response to this disaster, both in the short- and in the long-run. Overall, the analysis underlines the significance of local infrastructure networks to reduce the devastation inflicted by natural disasters.

This dissertation includes previously unpublished co-authored material.

CURRICULUM VITAE

NAME OF AUTHOR: Felix L. Friedt

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene, OR
Whitworth University, Spokane, WA

DEGREES AWARDED:

Doctor of Philosophy, Economics, 2017, University of Oregon
Master of Science, Economics, 2013, University of Oregon
Bachelor of Arts, Economics & International Business, 2012, Whitworth University

AREAS OF SPECIAL INTEREST:

International Trade
Industrial Organization
Econometrics
Transportation Economics

GRANTS, AWARDS AND HONORS:

Invited Participant, Western Economic Associate International Graduate Student Workshop, 2016

Gerlof Homan Graduate Scholarship in International Economics, University of Oregon, 2015

Charles A. Reed Graduate Fellowship, University of Oregon, 2014

Dale Underwood Award, University of Oregon, 2013

Best First-Year Econometrics Performance Award, 2013

Graduate Teaching Fellowship, University of Oregon, 2012-2017

ACKNOWLEDGEMENTS

I am very thankful for the support, guidance and advice I have received from Bruce Blonigen, Wesley Wilson, Anca Cristea and Jeremy Piger. I am grateful for many fruitful discussions with Taylor McKenzie, Michael Thacker and Joseph Wyer. Furthermore, I thank the participants at the University of Oregon IO and Micro Groups for many helpful comments and Dena Marshall for numerous edits of previous drafts of Chapters II and III. Earlier versions of Chapters II and III were presented in the TPUG sessions at the 2015 ASSA, 2015 WEAI and 2016 WEAI meetings. I thank the audience and, in particular, David Austin, Sharat Ganapati, William Huneke, Dennis Novy and Georg Schaur for their insightful comments. Any remaining errors are my own.

The financial support received through the Gerlof Homan Graduate Scholarship in International Economics is also gratefully acknowledged.

To my wife, Cassie Renée, and my parents, Maria-Anna and Gerhard Ludwig, for their unwavering support.

TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION

The primary focus of my research considers how transportation industries and their unique characteristics influence the patterns and composition of international trade, the effectiveness of trade policy and the resilience of international trade. Engaging in this research, I draw from the relevant elements of the extensive literatures on international economics and industrial organization. In the field of international economics, much of the literature is dedicated to the study of the determinants of international trade.[1] Barriers of trade have long been recognized as one of these major determinants and have received much academic and policy related attention (e.g. Hummels, 2001; Anderson and van Wincoop, 2004). Although transportation industries play an integral role in the facilitation of international transactions and the related costs exemplify a natural barrier to trade, most of the related literature focuses on artificial trade barriers, such as tariffs.

Recently, however, there has been a growing interest in transportation as a determinant of trade (e.g. Hummels and Skiba, 2004; Behrens et al., 2006; Hummels, 2007; Behrens and Picard, 2011; Deardorff, 2014). These studies demonstrate, both theoretically and empirically, that transportation costs are a central factor in the realm of trade costs and can influence the patterns of international trade. While distance has been used as the traditional proxy for transport costs, various studies, including for example Limao and Venables (2001) and Combes and Lafourcade (2005), have shown that it fails to capture significant variation concerning these costs. Surprisingly few studies have responded to these findings and provided a more careful treatment of the transport sector within a

---

[1] See, for example, studies by Deardorff (1998), Head et al. (2010) or Head and Mayer (2013).

model of international trade (e.g. Behrens and Picard, 2011; Takahashi, 2011; Ishikawa and Tarui, 2015).

In the first essay of my dissertation, co-authored with Wesley Wilson and entitled "Trade, Transportation and Trade Imbalances: An Empirical Examination of International Markets and Backhauls", we derive and estimate a model of international trade and transportation. Specifically, we develop a framework of international trade following Hummels et al. (2009) and incorporate a model of the international transport sector that accounts for the potential *backhaul problem* facing carriers facilitating international bilateral trade.[2] The theoretical findings show the simultaneity of trade and transport costs and co-integration of fronthaul and backhaul transport markets. Empirically, we use data from three different sets of markets that comprise the bulk of world trade and show that the simultaneity of trade and transport costs manifests itself in the existence co-integrating relations that govern the long-run equilibrium in the international container shipping industries. Simulations based on the estimated structural pricing relations and demand equations illustrate the potential spillover effects of international trade policy and demonstrate the significance of fronthaul and backhaul market co-integration.

The simultaneity of trade and transport costs in the presence of the backhaul problem highlights the transport sector as a potential policy avenue to stimulate international trade. In my second dissertation essay, entitled "Trade Policy Outcomes in the Presence of Asymmetric Transport Costs: Theory and Evidence", I build on these findings. In particular, I theoretically evaluate the potential impact of international carrier-cost-reducing policy on trade and test whether the presence of the backhaul

---

[2] The backhaul problem arises when carriers offer a transport service facilitating trade from location A to location B and, thereby, inadvertently create a transportation service available to facilitate trade from location B to location A, known as the *backhaul.* It becomes a *problem* for carriers when the demands for transport in markets AB and BA are imbalanced, such that transport capacity is not be fully utilized on the backhaul.

problem in the international transport sector influences the effectiveness of this trade policy. Theoretical derivations suggest that carrier-cost-reducing policies have larger effects on trade facilitated in backhaul rather than fronthaul transport markets and that the difference in these effects varies with the trade imbalance and across product groups.

Empirically, I test these theoretical predictions by estimating the effects of an exogenous shock to transport costs given by an EU environmental policy on U.S. containerized trade. I employ a large dataset obtained from the U.S. Census Bureau that contains trade flows at the U.S.-port-foreign-country level and augment it with employment statistics from various sources. Overall, the analysis produces novel theoretical and empirical findings that provide strong evidence that the presence of the backhaul problem causes systematic variation in policy effectiveness. The significance of these results follows from the sizable current U.S. trade deficit which prescribes that U.S. exports(imports) are primarily facilitated in backhaul(fronthaul) transport markets in recent decades. Given this imbalanced trade pattern, the evidenced variation in policy effectiveness has strong implications for policies that apply to the U.S. transport sector, such as the StrongPorts initiative by the Maritime Administration or the Trade Facilitation Agreement by the World Trade Organization (WTO).

In the final essay of my dissertation, entitled ”The Resilience of International Trade: An Empirical Examination of the Dynamic Spatial Trade Effects of Natural Disasters”, I investigate how the transportation network of U.S. seaports influences the response of U.S. trade to natural disasters. The central hypotheses of interest are whether or not international trade exhibits a static and/or dynamic resilience to natural disaster induced trade disruptions and what role infrastructure and transportation networks play in the determination of these resiliences. An extensive literature review highlights the gap in the current state of the literature and reveals that these important questions have not yet been addressed. Theoretically, I build on the traditional general equilibrium gravity equation and extend it to allow for the spatial and dynamic responses of disaster induced trade effects on international trade. Empirically, I test the resilience of trade estimating the spatial distribution and the dynamic response of U.S. containerized trade to Hurricane Katrina controlling for spatial correlations in the data. Various analyses of the U.S. port-level trade data point to very localized offsetting short-run as well as long-run disaster induced trade disruptions that underlie the aggregate resilience of international trade and evidence the importance of local transportation and infrastructure networks in shaping these responses.

My research contributes to both the international economics and industrial organization's literatures, and should be of considerable interest to researchers and policy-makers within these areas. While world trade has been growing at a rate faster than world GDP over the past decades (Blonigen and Wilson, 2013), more recent data reveal a relatively uncharacteristic downturn. In light of this recent development and the current political uncertainty concerning traditional commercial policies, my work points to transportation industries and infrastructure as an alternative policy instrument to stimulate trade. Moreover, my theoretical and empirical findings provide supporting evidence that the international transportation industries, in fact, influence trade policy effectiveness and are a cornerstone of the resilience of international trade.

CHAPTER II

TRADE, TRANSPORTATION AND TRADE IMBALANCES: AN EMPIRICAL EXAMINATION OF INTERNATIONAL MARKETS AND BACKHAULS

The present essay emanated from a term paper project I completed during Professor Wesley Wilson's Industrial Organization seminar. While Professor Wilson suggested the topic of the paper and provided initial points of reference in the literature, I compiled an extensive literature review on the issue of trade and transportation, refined the specific research questions addressed in this essay and developed the theoretical model underlying our analysis. Under my advisor's guidance, I refined the theory and significantly augmented the initially provided data. Having compiled the dataset, I derived the empirical model. Based on this model, I then conducted the empirical analysis researching the appropriate estimation techniques and finally implementing the advanced time-series econometrics discussed in the paper. While Professor Wesley Wilson contributed to various parts of this project, I believe it is fair to say that I took the lead on the development of this research and each of its aspects. From the initial analysis to the final write-up, I worked through each of the intricate details of this study.

Introduction

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

In the present study, I derive a model of transportation demand based on trade determinants and incorporate the supply-side, similar to Behrens and Picard (2011), with direct attention to the fact that most supply is provided between pairs of countries under conditions of joint production. I apply the model to three different sets of markets encompassing trade by container between Asia and the U.S., Asia and Europe, and the U.S. and Europe. The empirical tests employed in this study exhibit strong long-run relationships between trade and transportation that reflect the static equilibrium relations derived from the theory. The results point to the importance of freight rates in the determination of international trade and their respective dependence on the trade imbalance.

I estimate that in the long-run a 1% permanent increase in freight rates leads to a 0.06% permanent decline of trade, while freight rates show varying long-run responses to changes in the trade imbalance between two trading countries. The specific point estimates accentuate the importance of transportation in the determination of trade and highlight port and maritime transit policy measures as a key instrument to stimulate the growth of international trade. The primary contributions of this study are threefold. First, the presentation of a model that integrates trade and transportation with an explicit representation of the joint production present in the liner shipping industry and the ability to explain the large freight rate differentials observed between the U.S. and China, for example. Second, the estimation of the structural relationships that capture the long-run equilibrium conditions suggested by the theory. Third, simulations based on these estimates that highlight that the dependence of transportation costs on the trade imbalance can lead to spillover effects from policy across bilateral export and import markets.

Despite its importance to the determination of trade, historically transportation has played only a secondary role in the trade literature. In recognition of this gap in the literature, Behrens et al. (2006), Luo (2011) and Kleinert and Spies (2011) have integrated a transport sector into various models of trade. I extend this line of research by developing a model that combines the literatures on both trade and transportation. The trade framework follows Hummels et al. (2009), while equilibrium transportation costs are derived from the integration of a transport sector that follows the literature on the *backhaul problem*[1] by Wilson (1987), Wilson (1994) and Wilson and Beilock (1994). More specifically, I expand the model discussed by Hummels et al. (2009) by incorporating an international transport sector that accounts for the possibility of the backhaul problem faced by international carriers operating on bidirectional markets. I use this structural model to gain insights into the simultaneity of trade and transport costs as well as the effects of backhaul problem and show that there are potential spillover effects deriving from the cointegration of bilateral transport costs. This result compliments the findings by Deardorff (2014) illustrating that not only the presence of unit-specific trade costs, but also their cointegration can distort traditional trade theory results.

Empirically, I show that there are cointegration relations that establish the simultaneity between trade and transport costs suggested by the theory and govern the long-run equilibrium supply and demand conditions of the international transport markets facilitating international trade. The estimated cointegration equations provide long-run

---

[1] This 'problem' is an artifact of the market structure that freight carriers face. Allocating capacity and serving the transport market facilitating goods from country i to country j on a fixed round trip, inadvertently creates capacity to serve the transportation market facilitating trade from country j to country i. If this capacity available in the secondary backhaul transport market is not met with the demand for transport by shippers, it creates the, so called, backhaul problem for carriers that incur the joint cost of allocating capacity and serving the market pair ij.

structural relationships that support the general findings of static cross-sectional analyses in the trade literature. That is, trade between two trading regions is driven by aggregate income measures and reduced by trade costs. In particular, I illustrate that the estimated long-run equilibrium trade relation supports the general finding of unit elasticity of trade with respect to exporter and importer aggregate income, with point estimates ranging from 0.927 to 1.189 which are shown not to be statistically different from one at any conventional significance level.

In addition to that, the estimates demonstrate that, in the long-run, a 1% permanent increase in freight rates leads to, on average, a 0.058% permanent decline in trade. This relatively inelastic long-run response of the volume of containerized trade to an increase in unit-specific trade costs appears reasonable given the fact that container freight rates represent only a small fraction of the value of the goods shipped[2] but also masks the considerable changes in trade in absolute terms. That is, the results suggest that a $12.5 permanent increase in freight rates reduces the long-run volume of trade by 670,000 containers and the value of trade by $13 billion to $2 trillion depending on the containerized cargo.

Furthermore, the empirical results lend themselves for the evaluation of potential transport cost reducing policy measures and their long-run impact on trade. Simulations based on the coefficient estimates suggest, for example, that a persistent 10% increase in market shipping capacity is anticipated to permanently lower unit-specific trade costs in the form of container freight rates by 7.284% in fronthaul transport markets and 4.290% in backhaul transport markets. Based on the simulations, these long-run equilibrium

---

[2] According to the Rodrigue et al. (2013) the average value of a forty foot container ranges between $20,000 and $3,600,000 depending on the type of cargo. In contrast, the data show that average freight rates for a twenty foot container range from $835 to $1717 depending on the market.

reductions of freight rates coincide with a 0.321% permanent increase in fronthaul trade and a 0.189% permanent increase in backhaul trade.

The remainder of this paper is organized as follows: In section 2, I describe the institutional background of the container shipping industry. This background section is complemented by the literature review concerning the areas of trade, transportation and the integration of the two subjects and is presented in section 3. In section 4, I present a theoretical model of transportation markets. The empirical model is developed in section 5. Section 6 summarizes the data employed. These data exhibit dramatic differences across markets in terms of the level of trade imbalances and and freight rate differentials. Section 7 presents the empirical results which are generated from panel time series techniques. Indeed, the examination points to most of the variables having unit roots and the existence of long-run cointegration relations between trade and transportation. Section 8 provides a summary as well as conclusion and points to areas of further inquiry.

Institutional Background

Prior to modeling the international transportation markets of containerized shipments, a thorough analysis of the industry and its unique characteristics is imperative. In this section, I provide the information necessary to gain a basic understanding of the container shipping industry, its historical development and changing regulation.

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, world shipping capacity[3] as well as the capacity of individual

---

[3] By 2010, the global container shipping fleet was comprised of 4,677 vessels with a maximum capacity of 12.8 million twenty-foot equivalent units (TEUs) (UNCTAD, Secretariat, 2014)

vessels has grown to match this demand. In 1956, 58 trailer-truck bodies were transported on board of the *Ideal X*. By 2006, it was not uncommon for vessels to carry over 9,000 twenty-foot equivalent units (TEUs) (Transportation Research Board, 2006). More recently, however, Port Finance International (2013) reports, that this capacity has been more than doubled by the largest container vessel, the triple E-class, operated by Maersk, with a capacity of 18,270 TEUs per ship.

In light of such rapid and recent developments, the question of how a seemingly inconspicuous innovation like a metal container has been able to revolutionize international trade becomes interesting and intriguing. The answer to this question lies within the costs associated with international trade. Internationally traded goods must be transported between the two trading regions. In many cases this implies that the goods have to be shipped long distances between the U.S., Europe, and Asia. The freight rates and related charges associated with these shipments are an integral part of international trade costs and have been strongly influenced by the introduction and adoption of the container.[4]

Due to the importance of this industry, in 1961, the Federal Maritime Commission (FMC) was charged with the regulatory oversight of the U.S. liner shipping industry. The goal in establishing the FMC has been to ensure that no unfair business practices by the liner groups or foreign governments harm American consumers of imported goods or American exporters. With the beginning of containerized shipments in 1956, the FMC was instated in the wake of this revolutionizing innovation and had to reevaluate the existing regulation set forth in the Shipping Act of 1916. This reevaluation led to the Shipping Act of 1984. The dilemma the FMC had to address was the disconnect between promoting

---

[4] Jacks et al. (2008), for example, find that trade costs play a varying role in the determination of trade growth over the past two centuries. In particular, authors find that the reduction in trade costs post world war II has contributed about 33% of total trade growth.

competitive freight rates, while allowing conferences to set market rates high enough to ensure sufficient supply of carrier capacity to support growing U.S. trade flows.

The Shipping Act of 1984 limited the power of ocean common carrier conferences over each member. Conferences could no longer prohibit its carrier members from privately negotiating a service contract with a shipper. This policy reform was completed in 1998 with the passing of the Ocean Shipping Reform Act (OSRA). Although the limited antitrust immunity of carrier conferences remained, the industry was further deregulated under OSRA. Conference members were not only allowed to privately negotiate contracts determining the pricing terms, but OSRA also prohibited the conferences from requiring disclosure of such contracts.[5]

This deregulation has led to the restructuring of the global liner[6] shipping industry.[7] 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 U.S. Eastbound Freight Conference (JUEFC), which previously controlled some of the freight rates charged on Trans-Pacific trade routes, were suspended. Further deregulation of the liner shipping industry has not only been initiated by the FMC, but has been a global issue, instead. In 2006, the EU repealed the block exemption from EU

---

[5] "(...) With respect to agreements, OSRA has maintained antitrust immunity for concerted carrier actions, but has limited the permissible activities to which such immunity attaches. Agreements no longer may limit or prohibit service contracting by their members. Moreover, agreements are precluded from requiring members to disclose their service contract negotiations or the details of any contracts into which they have entered. An agreement may publish general guidelines applicable to members' individual contracting practices, but these guidelines must be voluntary and non-enforceable by the agreement and filed confidentially with the Commission. (...)" Federal Maritime Commission et al. (2000, p.3)

[6] According to the World Shipping Council liner shipping encompasses all modes of high capacity transport services. Moreover, liner vessels are primarily containerships. Thus, the deregulation of liner shipping directly applies to the containerized freight studied in this paper.

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

competition law that it had provided for the liner shipping conferences in EU trades. This new law became effective in 2008 and led to the termination of the Transatlantic Conference Agreement (TACA).

Today's container shipping industry is comprised of many different firms incorporated all over the globe, holding capacity shares ranging from less than 0.02% to 14.7%[8] of the global capacity measured in TEUs. After the demise of the P3 alliance[9], there are currently nineteen major competitors each holding more than 1% of global capacity shares. Most notable is the largest competitor in this industry, Maersk, holding 14.7%. Combined, these nineteen firms account for over 82% of the global container shipping capacity, while the remaining market share is scattered across many smaller carriers. Considering these market shares raises the question of how the Shipping Act of 1984 and OSRA have shaped the market structure in this industry and how much market power is currently exercised by container carriers? Furthermore, the question of how the current market structure influences the dynamics that determine international container freight rates becomes of central interest.

The interplay between trade and transportation that gives rise to the demand and supply of the international transport sector and determines the asymmetric unit-specific trade costs given by container freight rates, is the central issue analyzed throughout the remainder of this study. The following section gives an overview of the existing literature on international trade and its associated trade costs as well as the existing literature analyzing transportation markets. Following these separate literature reviews, I present a summary of the existing literature that develops and tests the theoretical and empirical

---

[8] Source: Alphaliner - TOP 100 Operated fleets as per April 11th, 2016

[9] The P3 alliance was a planned cooperation between Maersk, Mediterranean Shipping Co., and CMA CGM, the three largest competitors world wide, on the major east-west trade routes. However, after a year of negotiations, China denied regulatory approval of this alliance and thereby, led to its demise.

interconnections between international trade and transportation markets with a particular focus on the liner shipping industry.

Literature Review

In order to accurately model the international transport sector and integrate it into a model of international trade, a clear understanding of the theoretical and empirical developments in the fields of international trade as well as transportation economics is necessary. This literature review aims to provide such an understanding, first highlighting the major developments in international trade and subsequently focusing on the advancements in the field of transportation economics. For the research purposes of this study, the overlap between the two fields of international trade and transportation economics is of special interest. To this end, the third section of this literature review is dedicated towards a concise summary of the historical and recent progress in combining the two areas of research. In conclusion of this section, I highlight the remaining gaps in this strand of the literature and describe how this study contributes towards the closure of these gaps.

International Trade

There is a plethora of different models of international trade. Some of the underlying foundations of these models include 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. Empirically, the workhorse for modeling trade has been the gravity model introduced by Tinbergen (1962), which takes trade between countries as a function of GDP and trade cost measures, such as distance between the two countries. The resulting gravity equation, which can be derived from a multitude of trade models, has been one of the key instruments used to empirically analyze the determinants of trade flows. There are many applications for which the gravity equation has been utilized.[10] One of the key results highlighted by both the theoretical and empirical studies is the dependence of trade on international trade costs.

Regardless of the differences between Krugman's *New Trade Theory*[11], Anderson and van Wincoop's gravity equation[12], or the *New New Trade Theory* based on the Melitz model of trade[13] (Melitz, 2003), all of these models incorporate symmetric trade costs. Through the theoretical derivation of each of these models, trade costs have been established to be a major determinant of international trade. Obstfeld and Rogoff (2001) go as far as claiming that all remaining macroeconomic puzzles identified in their research critically hinge on trade costs.

Early empirical studies simply controlled for trade costs via distance between two trading regions. However, as the trade literature has advanced, focus has shifted towards a more careful integration of trade costs and its individual components. Anderson and van Wincoop (2004) survey the literature and establish that trade costs are equivalent

---

[10] See, for example, surveys by Bergstrand and Egger (2011) or Anderson (2011) and applications by Bergstrand (1985), Thursby and Thursby (1987), McCallum (1995), Anderson and van Wincoop (2003) and Carrere (2006).

[11] Krugman is credited with the introduction of the *New Trade Theory*, due to his research on the patterns of trade and role that economies of scale play in the determination of these patterns (Krugman, 1980)

[12] Anderson and van Wincoop (2003) provide a theoretical derivation of the gravity equation that stresses the importance of multilateral resistance terms.

[13] In his 2003 article, Melitz incorporates heterogeneous firms into a trade model and thereby, provides the theoretical basis for a new trend in the international economics literature that focuses on the role that individual firms with varying productive efficiencies play in the determination of trade, labeled as the *New New Trade Theory.*

to a 170% ad valorem tax of a representative rich country. Furthermore, the authors point out that trade costs can be divided into three main categories, which include border related costs, local distribution costs and, most importantly for this study, transportation costs.[14] In particular, according to the authors, 21% of all trade costs are attributed to transportation costs.[15]

In addition to these empirical findings, it is important to point out that the majority of international transactions are facilitated by seaborne transportation services. According to Rodrigue et al. (2013), as of 2008, roughly 90%[16] of the volume, measured in shipped tonnage, and about 73% of the value of international trade was handled by seaborne transportation. As container shipping is one of the major contributors to seaborne transportation[17], these figures highlight the importance of the international container shipping industry in explaining trade costs and motivates my research in this particular industry.

---

[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.

[15] Anderson and van Wincoop (2004) point out that this is a rough estimate, and, indeed, there is some debate over the true effects of transport costs and trade liberalization on trade flows and growth. While Baier and Bergstrand (2001) find that the reduction of transport costs contribute only 8% of total trade growth, compared to 33% due to trade liberalization, 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. Furthermore, Hummels (2007) points out that transportation costs on U.S. imports far outweighed the costs imposed by tariffs in 2004. However, Hummels (2007) argues that the cost reduction of air rather than seaborne transportation has been a critical factor driving the second era of globalization.

[16] The data used by Rodrigue et al. (2013) was obtained by IHS. Global Insight, Inc., World Trade Services and does not include intra-EU trade.

[17] According to the U.S. Department of Transportation Maritime Administration (2013) containerized trade, measured in metric tons, accounted for 18.1% of total U.S. waterborne trade in 2011.

Transportation Economics

Transportation economics have a rich background within the Industrial Organization literature. The field spans several different industries besides the international liner shipping industry, such as railroads and trucking, for example. This subsection will highlight advances in a variety of industries, while pointing to the potential overlap and applicability, as well as the limitations of the theoretical and empirical results obtained across these industries.

One of the earlier works, which directly ties into the liner shipping industry, is the study by Nicholson (1958), who analyzed the minimum rate regulation in the California trucking industry. The author finds that one of the main shortcomings of the regulation was the fact that the minimum rate assessment did not incorporate the joint cost component that exists when serving two markets linked by a round trip. This joint cost component is one of the key elements to modeling the liner shipping industry. A carrier operates on round trips and has to take the inseparable joint cost associated with providing capacity to a transport market pair into account.

Since then, the issue of joint costs has been connected to the backhaul problem in various transportation industries and has received a fair amount of attention in the previous literature. Basemann and Daugherty (1977), for example, claim that an insignificant differential in costs between empty and full backhauls allows the backhaul to be viewed as a complementary good of the fronthaul. The simple general equilibrium model employed by the authors shows the existence of a competitive equilibrium with empty backhauls, while regulation is shown to be inconsistent with empty backhauls. However, this result is only obtained at backhaul freight rates equal to zero which in turn is only feasible if the additional marginal cost between full and empty backhauls tends to zero. The freight rate differentials observed in the container shipping industry reflect a similar pricing behavior, although backhaul rates are on average statistically different from zero.[18] This observation is intuitive when considering the dimensions of seaborne transportation. Although there may be small differences between the cost of moving an empty and a fully loaded container per mile traveled, these differences add up quickly when considering vessels that carry 10,000 or more containers and travel over 6,000 miles on the backhaul leg.

Demirel et al. (2010) introduce search time as a market friction to overcome this issue. The authors use a matching model to demonstrate that backhaul rates of inland barge shipments depend on the search time spent by carriers. Since search times are costly, this market friction provides a theoretical explanation for non-zero backhaul rates that are suggested by Basemann and Daugherty (1977). With the inclusion of search costs, this study hints at the importance of accurately each of a given carrier's cost components.[19]

As previously noted, the issue of empty backhauls from a major importing region is not unique to the container shipping industry. The trucking industry, for example, faces the same issue of empty backhauls on a much smaller scale and generally at a domestic level. Again, the main problem is described by binding capacity constraints on the fronthaul and uncertain and insufficient demand for transportation on the backhaul. Wilson (1987) analyzes firm behavior under this uncertainty. In particular, he studies trucking firms' decisions to serve markets under the ICC regulation and varying backhaul probabilities. Jordan (1987) presents two alternative mathematical models to analyze the trucking industry operating on networks with multiple nodes. He finds that the

---

[18] Average freight rates by market are provided in Table 1.

[19] One example of a careful treatment of transportation costs is the study by Baumol and Vinod (1970). The authors introduce a thoroughly developed cross-industry cost structure, in order to study the modal choice of shippers and derive the demand for transport from an inventory theoretic model.

heuristic model he sets up minimizes the empty truck miles under the restrictions that only one backhaul load can be carried and that the backhauls between terminal pairs must be balanced. Rietveld and Roson (2002) develop a monopolistic model addressing the backhaul problem and direction dependent pricing. Their main finding is that price restricting policies that limit the discriminatory pricing of the monopolist can lead to an overall welfare loss, where both the supplier and average consumer lose. All of these papers relate to the container shipping industry in certain aspects. Seaborne vessels travel in round trips between two trading regions and face uncertainty about the backhaul demand. Due to this uncertainty, it is common practice that prices depend on the direction of trade flow and can exhibit large differentials within a given market pair.

However, as the research by Felton (1981) shows, the trucking industry is subject to a set of regulations that not only heavily influences trucking freight rates and the commodities transported, but is also very different from those regulations[20] the container shipping industry must comply with. Even after the trucking deregulation through the late 1970's and the Motor Carrier Act of 1980, Wilson and Beilock (1994) find that the remaining entry regulation has a significant effect on the access of regulated markets which continues to cause empty backhauls. In addition, Wilson (1994) documents that the trucking regulation leads to underutilization and displacements of capacity across varying markets. The dynamics created by the remaining trucking regulation, although similar to those found in the container shipping industry, come about for very different reasons. Therefore, a cross-industries comparison, drawing conclusions over the container shipping industry, might be quite misleading.

---

[20] See the previous discussion of the institutional background of the container shipping industry and Federal Maritime Commission et al. (2000) for further regulatory detail.

Liner Shipping Industry

Due to these distinct differences that set the liner shipping industry apart from other transportation industries and because of its importance concerning the facilitation of international transactions, it has been the subject of a variety of economic research. One strand of this research, for example, focuses on the impact of containerization on global economic developments. One of the seminal studies in this literature is the book, titled "The Box", by Levinson (2010). In his book on the evolution of containerized shipments, the author points out that one of the most contributing factors to the development of the world economy has been the sharp reduction in freight rates caused by the cost savings incurred due to containerization. While this observation alone raises many research questions of great importance, the attention liner shipping has received historically has been rather small. Perhaps the reason for this lack of discussion of the container, among all the other 20th century innovations, is due to the gradual adoption of this costly technology. In her research, Rua (2012) studies the effects of fixed costs and networks on the adoption rate of containerized shipping. The author finds that the adoption is driven by a country's volume and expected volume of trade, as well as the country's institutions and ties to other trading partners utilizing containerized shipments.

Other research revolving around the liner shipping industry has focused on the price setting behavior of carriers and carrier conferences. Historically, prior to the deregulation of the industry, the concern of the Federal Maritime Administration has been the price discrimination imposed by liner conferences acting under antitrust immunity. Heaver (1973), Lipsey and Weiss (1974) as well as Talley and Pope (1985) all analyze the price setting behavior of liner conferences to find the main determinants of container freight rates and evaluate the accusation of price discrimination. One of the general findings is that freight rates depend on the characteristics of the cargo shipped, which could potentially imply price discrimination. Sjostrom (1992), however, argues that some of the previous estimations have utilized a reduced form equation that suffers from simultaneity bias which undermines these findings. In his view, it has not been established whether liner conferences are price discriminating. Furthermore, the author claims that additional investigation into independent variables that only affect the demand for transport without affecting carrier costs, is necessary to remove ambiguity and overcome the simultaneity bias. In summary, these studies indicate the driving factors behind liner price setting and demonstrate the difficulty in accurately modeling the liner shipping industry.

The potential price discrimination by carrier conferences is not the only issue that has sparked interest in container freight rates. Freight rate differentials across varying market pairs have also drawn attention. The study by Fan et al. (2014) presents a nonstructural time series analysis of the freight rate differentials and the cointegration of the joint prices of fronthaul and backhaul. Through this time series analysis of the liner shipping freight rates, the authors find that cointegration depends on the trade imbalance and that the imbalance threshold for cointegration changes between regional market pairs. Generally, a larger trade imbalance reflects a higher probability of an empty backhaul and is observed to be correlated with disintegrated freight rates. This disintegration stems from the fact that the joint costs of providing capacity to a transport market pair serving on a round trip between two countries is no longer shared between the individual transport markets, but is, instead, completely allocated towards the fronthaul market.

These empirical investigations of liner shipping freight rates are complemented by several studies that have developed theoretical models that incorporate the specific dependencies of freight rates on trade imbalances as well as trade volumes. These studies have started the integration of transportation economics into trade frameworks and are presented in the following subsection.

International Trade and Transportation

As previously discussed, transportation is an integral determinant of international trade. In addition to that, transportation industries exhibit several interesting dynamics that lead to asymmetric trade costs and thus, heavily influence overall trade flows. Samuelson (1952) was one of the first to analyze the effects of transportation costs between trading regions on the equilibrium level of trade. Since his introduction of the 'ice-berg' transportation cost[21] to the trade literature (Samuelson, 1954), it has been widely used for its tractability and implicit inclusion of transportation costs.

The renewed focus on trade costs has brought about a few research efforts that have studied the effects of endogenously determined transportation costs within a given trade model. Some of these models still rely on the iceberg cost structure, while others explicitly model the additive rather than proportional nature of transport costs in the determination of export prices. Luo (2011) as well as Kleinert and Spies (2011) explicitly model the transport sector within the given trade framework. Luo (2011) continues the traditional use of iceberg trade and transport costs. He develops a trade cost index (TCI) and provides empirical evidence that the TCI is a better proxy for trade costs than distance. Kleinert and Spies establish the simultaneity between trade and transportation costs via an investment decision faced by transportation firms. In this model higher trade volumes encourage transportation firms to incur higher fixed costs to invest in cost reducing technology. Thus, the resulting drop in transportation rates is caused by an increase in the trade volume, which in turn is positively affected by the reduction in transportation costs.

---

[21] "The simplest assumption is the following: To carry each good across the ocean you must pay some of the good itself. Rather than set up elaborate models of a merchant marine, invisible item, etc., we can achieve our purpose by assuming that just as only a fraction of ice exported reaches its destination as unmelted ice, so will (...) fractions of exports (...) reach the other country as imports." (Samuelson, 1954, p. 268)

These models suggest that, regardless of the specific assumptions made, transportation is endogenous to the determination of trade. Due to this endogeneity, many papers have empirically analyzed the impact of trade flows and imbalances on transportation rates. Clark et al. (2004), for example, carefully integrate a variety of determinants of transportation rates into their model. They find empirical evidence that supports the theoretical predictions. Distance and trade composition increase freight rates, whereas trade imbalances and economies of scale, captured through vessel size, have a negative effect on these rates. Furthermore, the authors show that port efficiency, which is measured by the GCR index[22], and infrastructure are strong determinants of the transportation rates. In particular, the authors' main finding is that an increase in port efficiency from the 25^{th} to the 75^{th} percentile leads to a decrease in transportation rates of 12%. Wilmsmeier et al. (2006) extend this study by additionally controlling for private sector participation, inter port connectivity, and customs' delays. However, the authors fail to instrument for trade volumes, thereby ignoring the endogeneity concerns suggested by the theory. Despite the issue of endogeneity in the latter study, both of these research studies point to the transportation sector and ports, in particular, as an excellent policy avenue that can have real effects on trade costs and thus, trade flows. The empirical results found in the this study support this general finding and furthermore, suggest that there is a long-run relationship between trade and transportation that can be exploited through maritime transportation policy.

Theoretically, Andriamananjara (2004) explores this policy avenue through a model of the international transport sector (ITS) that lends itself to the theoretical evaluation of the effects of a variety of ITS oriented policy measures on transport rates. She demonstrates that increased competition and deregulation are complementary policy

---

[22] The Global Competitiveness Report (GCR) was developed by the World Economic Forum in 1999.

tools. More importantly, the author shows that multilateral policy efforts can be more sustainable than unilateral ones due to the positive effects of increased trade flows caused by a reduction in transportation costs. Francois and Wooton (2001) develop a theoretical model that complements these results. Testing their model, the authors find that the gains from trade to consumers and producers are heavily dependent upon the market structure in the shipping industry. In particular, a more competitive shipping industry leads to higher pass through gains from trade liberalization. Hummels et al. (2009) present additional empirical evidence for Adriamananjara's finding that increased competition leads to lower transportation rates. Specifically, Hummels et al. (2009) find that the international shipping industry exhibits market power that allows for mark ups to drive up transportation rates. The authors identify the market power via uniform tariff changes that lead to differential price setting behaviors.

Behrens et al. (2006) are the first to endogenize iceberg transportation costs within a new economic geography model. The authors utilize 'iceberg-like' trade as well as transport costs by measuring the cost in terms of the numeraire commodity. Behrens and Picard (2011) develop an alternative model that incorporates the same joint dependence of trade flows and transport costs via a capacity constraint. The authors' main finding is that endogenous transport costs dampen the Home Market Effect.[23] Takahashi (2011) provides additional support for this finding through another theoretical approach, while still relying on iceberg transportation costs. In accordance with Behrens and Picard (2011), the author finds that trade imbalances between two regions lead to freight rate differentials which in turn, inversely affect trade imbalances and thus, lead to a dispersion force on economic activity.

---

[23] The Home Market Effect(HME) represents the concentration of an industry in the country that exhibits the largest domestic demand to take advantage of economies of scale and minimize transportation costs. The HME was incorporated into the New Trade Theory through Krugman (1980).

These theoretical findings are complementary to the results obtained by Jonkeren et al. (2011), who study the effects of trade imbalances between European trading regions on the freight rates charged on inland waterways. Accounting for the endogeneity of trade imbalances, the authors find that an increase in the imbalance between region A and B leads to an increase in the rate charged from A to B. In contrast to this result, Tanaka and Tsubota (2014) find that a 10% increase in relative exports between Japanese prefectures leads to a 2.1% decrease in the freight rate charged on that route. The authors claim that, in this case, the effects of density economies dominate the trade imbalance effect. Regardless of the dispute over the sign of the impact, all of these studies highlight the endogeneity of transportation costs in the determination of trade flows.

Following these recent advancements, the theoretical model developed in this study links international trade and transportation by explicitly deriving the demand for transport from a trade framework and carefully developing the supply side of the transport sector accounting for the dynamics of joint production. As in previous studies, this inclusion of a separate transport sector effectively endogenizes transport and thus, trade costs. Similar to a few select papers mentioned above, the model I develop next incorporates the round trip nature of the international transportation industry and points to the simultaneity of trade and transportation costs. Empirically, I apply this theoretical model to three market pairs between the major trading regions of the U.S., EU and Asia and evaluate it using time series techniques. In particular, I estimate the panel cointegration equations underlying the demand and supply relations which govern the long-run structural relationships between trade and trade costs suggested by the theory. To the best of my knowledge, this analysis is a novel contribution to the literature offering new insights into the dynamics of this important industry and lends itself for the evaluation and simulation of the long-run effects of trade and transportation policy on the equilibrium levels of trade and potential spillover effects from these policies across bilateral export and import markets.

Theoretical Model

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

Demand for Transport

To begin, I derive an expression of the demand for transport from the international trade theory expressed by Hummels et al. (2009). In this model of trade, each country, j=1,2,...,M, is composed of one representative consumer. Preferences of each representative consumer take a quasi-linear form and are expressed over a homogeneous numeraire commodity and a variety of a good that is differentiated by national origin, as in Armington (1969). The price elasticity of demand, σ, is assumed to be constant across representative consumers and greater than one. Given these assumptions, the preferences of the representative consumer in country j can be expressed by the following utility function

$$U_j = q_{0j} + \sum_{i=1}^{M} q_{ij}^{(\sigma-1)/\sigma} \quad \forall j = 1, .., M, \tag{2.1}$$

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 domestic sales price of a variety from country i is represented by p_i and taken as given by carriers. Given the fact that each representative consumer has a taste for variety[24] and goods are differentiated by origin, there is an incentive for trade, and trade between countries introduces the international transportation markets. Indeed, trade costs in the form of freight rates become a determinant of the equilibrium. And, a complete model incorporates the transportation supply to allow the equilibrium transport rates to be endogenously determined along with trade. In fact, given that each country engages in trade, the import price, p_{ij}, of a variety from country i paid by the representative consumer in country j includes per-unit transportation costs, f_{ij}, and the ad-valorem trade costs, $\tau_{ij} \geq 1$, in addition to the sales price, p_i. That is, $p_{ij} = p_i\tau_{ij} + f_{ij}$, where the transport and ad-valorem trade costs are taken as given by each representative consumer.[25]

Utility is maximized by each representative consumer with respect to their budget constraint. The solution to this constrained optimization problem gives the imported

---

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

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

quantities by country j from each country i. These imports also represent the demand for transport from each country i to country j and are given by the following expression;

$$q_{ij} = \left[\frac{\sigma}{\sigma - 1}(p_i \tau_{ij} + f_{ij})\right]^{-\sigma} \quad \forall i, j = 1, .., M, i \neq j. \tag{2.2}$$

Of course, this expression for the demand of transport holds for any two countries i and j engaged in bilateral trade and naturally creates the transport market pair ij for each carrier. However, it is important to make note of the fact that transport demands do not have to be equal to one another. In fact, trade flows are rarely equal. Most often country i is a net exporter to country j. This trade imbalance particularly holds for containerized cargo flows which implies that demands for transportation in the market pair ij are imbalanced.[26] 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*.[27]

Supply of Transport

In this study, the theoretical and empirical analyses specifically apply to containerized traffic between regional pairs and focuses on the overall effect of transportation costs on trade flows and imbalances under the dynamics of joint production. More formally, each carrier allocates capacity K to transport market pair ij, in order to offer transport supply, $Q_{ij} \leq K$, to transport market ij and facilitate trade from country i to country j. Given that carriers operate on strictly scheduled

---

[26] 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.

[27] Obviously these terms are inaccurate. By definition, fronthaul and backhaul depend on the trade imbalance between two regions rather than the direction of trade flow or the starting point of a round trip.

round trips[28], serving transport market ij inadvertently allows the same carriers to offer transport supply, $Q_{ji} \leq K$, in transport market ji to facilitate trade from country j to country i. Due to inseparable joint costs that arise from providing capacity to serve the transport market pair ij, these transport supplies are joint products.

When the demands for these joint transport supplies are imbalanced, adherence to strict schedules prohibits the allocation of search and/or waiting time for additional cargo and forces carriers to adjust transport supplies accordingly. In equilibrium, this results in transportation costs that adjust to the existing demand imbalance.[29] These market frictions resulting from the joint production and tight schedules introduce the key dynamics that separate this theoretical model of a transport sector from the majority of the previous work in the trade literature and extend the model developed by Hummels et al. (2009).

I model the international shipping industry to exhibit market power. To accommodate this feature of the industry and following the derivation by Hummels et al. (2009), the transport sector is modeled as an oligopoly consisting of $l = 1, ..., N$ symmetric carriers competing in Cournot fashion. Extending the given model, I assume that each carrier, l, serving the transport market pair ij facilitates a portion of bilateral trade, q_{ij} and q_{ji}, between countries i and j and has a round trip cost structure that is twofold. In particular, similar to Wilson (1994) and Wilson and Beilock (1994), each carrier faces market specific access costs, a_{ij}, such as additional fuel or terminal costs, for shipping

---

[28] 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.

[29] Individual carriers may serve multiple locations on a single round trip or take advantage of hub and spoke shipping networks to reduce the backhaul problem. However, as the cargo flows depicted in Figures 2b, 2d, and 2f reveal, severe aggregate traffic imbalances prevail despite the potential for such strategies. Thus, for expositional purposes, I assume that each carrier serves only two regions with each round trip. Generalization to multiple locations is straight forward.

one unit of a variety from country i to country j. In addition, each carrier's technology is further defined by the previously mentioned joint costs, $JC(K^l)$, with $JC(0) = 0$ and $\frac{\partial JC(K^l)}{\partial K^l} > 0$. These costs of providing capacity include, for example, labor, maintenance and repairs, or insurance costs that are not differentiable between the individual transport markets and can be viewed as, quite simply, the costs of traveling between the two locations. Therefore, each carrier's round trip costs can be expressed as follows:

$$C^l = a_{ij}Q^l_{ij} + a_{ji}Q^l_{ji} + JC(K^l) \ \forall l = 1, ..., N \ and \ i, j = 1, ..., M, \ i \neq j. \tag{2.3}$$

Given this cost structure, each carrier chooses the profit maximizing transport 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.[30] Each carrier's profit from a given round trip between country i and country j can be written as

$$\begin{aligned} &\max_{K^l, Q^l_{ij}, Q^l_{ji}} \Pi^l = f_{ij}Q^l_{ij} + f_{ji}Q^l_{ji} - C^l \quad \forall l = 1, ..., N \text{ and } i, j = 1, ..., M, \ i \neq j, \\ &\text{subject to } K \geq Q_{ij}, \ K \geq Q_{ji}. \end{aligned} \tag{2.4}$$

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

---

[30] Of course, the dimensionality of each carrier's optimization problem can be extended to include issues, such as the dependence of carrier costs on the actual port of entry or uncertainty concerning the reliability of the hinterland transportation network. Although these issues are important, they go beyond the scope of this paper. Therefore, I abstract from issues of uncertainty and limit the theoretical analysis to a one port per country model.

can be represented as follows;

$$
\begin{aligned}
\frac{\partial \Pi^l}{\partial Q^l_{ij}} = f_{ij} + Q^l_{ij}\frac{\partial f_{ij}}{\partial Q^l_{ij}} - a_{ij} - \lambda_1 \leq 0 &\quad \text{with} = \text{if } Q^l_{ij} > 0 &\quad \forall l = 1, ..., N &\quad (2.5a)\\
\frac{\partial \Pi^l}{\partial Q^l_{ji}} = f_{ji} + Q^l_{ji}\frac{\partial f_{ji}}{\partial Q^l_{ji}} - a_{ji} - \lambda_2 \leq 0 &\quad \text{with} = \text{if } Q^l_{ji} > 0 &\quad \forall l = 1, ..., N &\quad (2.5b)\\
-\frac{\partial JC(K^l)}{\partial K^l} + \lambda_1 + \lambda_2 \leq 0 &\quad \text{with} = \text{if } K^l > 0 &\quad \forall l = 1, ..., N &\quad (2.5c)\\
K^l \geq Q^l_{ij} &\quad \lambda_1 \geq 0 &\quad (K^l - Q^l_{ij})\lambda_1 = 0 &\quad (2.5d)\\
K^l \geq Q^l_{ji} &\quad \lambda_2 \geq 0 &\quad (K^l - Q^l_{ji})\lambda_2 = 0. &\quad (2.5e)
\end{aligned}
$$

The first oder conditions with respect to transport supplies, given by equations (2.5a) and (2.5b), can be seen as each carrier's market access conditions indicating that marginal revenues in either transport market must cover access costs for a given market to be served. In addition to that, each carrier's first order condition with respect to allocated capacity can be interpreted as the service condition. That is, given the fact that the Kuhn-Tucker multipliers, 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 (2.5c) states that the total value of an additional unit of transport supply in either market must equal the marginal joint costs of the additional capacity to be allocated and the market pair to be served at all.

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

$$q_{ij} = \sum_{l=1}^{N} Q^l_{ij} \tag{2.6a}$$

$$q_{ji} = \sum_{l=1}^{N} Q^l_{ji}. \tag{2.6b}$$

Combining the demand for transport given by equation (2.2), the first order and Kuhn-Tucker conditions given by (2.5a)-(2.5e) and the market clearing conditions represented by equations (2.6a) and (2.6b), several equilibrium solutions can be obtained. While the details of the derivation are fairly standard, there are a few aspects of the set of solutions that are important to point out. First, given this model, it can be shown that at least one of the capacity constraints, $K^l \geq Q^l_{ij}$ and/or $K^l \geq Q^l_{ji}$, must be binding in any equilibrium solution. This implies that any solution to this static model is characterized by full capacity utilization in at least one of the two transport markets. While additional considerations, such as the time that it takes to build a container vessel to adjust capacity, may introduce market frictions that lead to non-binding capacity constraints in the short-run, full utilization of allocated capacity is a sensible feature for any of the long-run equilibrium cases derived from this model.

Second, the set of solutions includes equilibrium cases, where optimal transport supplies and international trade are zero valued when marginal joint and/or access costs are prohibitively high for the transport market pair or either of the individual transport markets. For the purposes of this study, the remaining analysis solely focuses on cases where equilibrium transport supplies and international trade are positive in both transport markets. Third, equilibrium solutions involving positive unilateral or bilateral international trade exist and can be derived in symmetric pairs that simply interchange the i and j notation. Thus, without loss of generality, I treat the transport market facilitating trade from country i to country j as the fronthaul and the transport market facilitating trade from country j to country i as the backhaul for the remainder of the analysis.

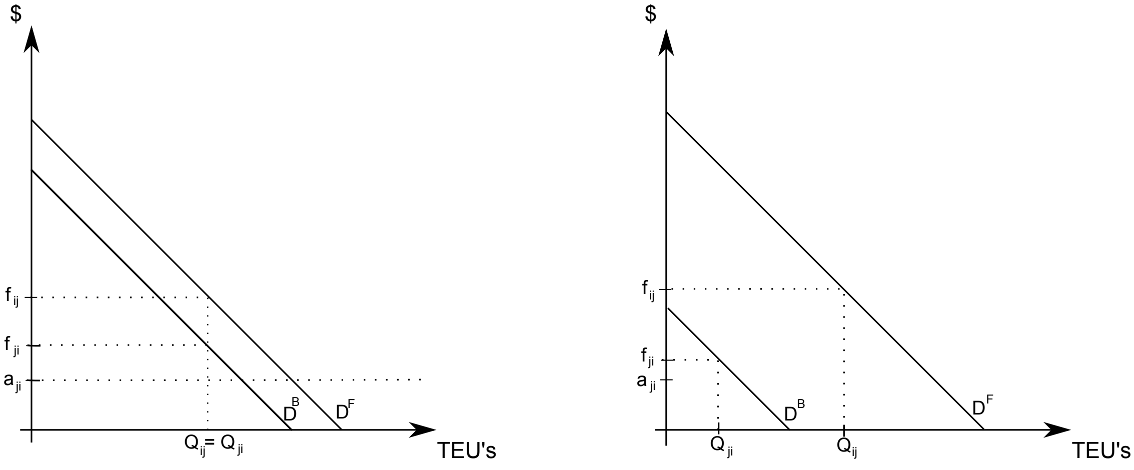
Equilibrium Considerations

Given non-prohibitive access and marginal joint costs in fronthaul and backhaul transport markets, the solution to the model has to distinguish between the balanced and imbalanced trade case. Naturally, the consideration of whether the balanced or imbalanced trade equilibrium arises, heavily depends on the imbalance concerning the demands for transport. Given equation (2.2), this demand imbalance can be represented and rewritten as follows;

$$q_{ij} \geq q_{ji} \implies p_j \tau_{ji} - p_i \tau_{ij} \geq (f_{ij} - f_{ji}). \tag{2.7}$$

As equation (2.7) shows, the size of the trade imbalance depends on the difference in domestic sales prices as well as the endogenously adjusting freight rate differential. Intuitively, small differences in the bilateral demands for transport, due to small sales price variations across country i and j, may allow carriers to choose equal transport supplies that maximize capacity utilization in both transport markets. The resulting equilibrium freight rate differential must offset any price differences, so that bilateral trade balances. Large imbalances concerning the bilateral demands for transport caused by substantial differences in sales prices between two countries, however, may force carriers to choose asymmetric transport supplies with excess capacity in the backhaul market. The resulting equilibrium freight rate differential does not offset the sales price variation and leads to imbalanced bilateral trade. In fact, it can be shown that a balanced trade equilibrium only arises when $p_j \tau_{ji} - p_i \tau_{ij} \in \left(a_{ij} - a_{ji} - \frac{\partial JC(K^l)}{\partial K^l}, a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} \right)$, whereas an imbalanced trade equilibrium, where exports from country i to country j exceed exports from country

j to country i, results when $p_j\tau_{ji} - p_i\tau_{ij} > \left(a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right)$. [31] Both of these two scenarios can be summarized graphically and are depicted by Figures 1a and 1b.



(a) Balanced Trade

(b) Imbalanced Trade

FIGURE 1. Linkages between Trade Balance and Transportation Cost Differentials

Figure 1a demonstrates the balanced trade case. In this scenario, the difference between fronthaul demand, D^F, and backhaul demand, D^B, is rather small. Given this small difference in demands for transport, each carrier's optimal choice leads to symmetric transport supplies, $Q^l_{ij} = Q^l_{ji}$, which in turn leads to asymmetric equilibrium freight rates, $f_{ij} \neq f_{ji}$. As Figure 1a shows, the size of the potential freight rate differential depends on the actual imbalance of the demands for transport. Furthermore, Figure 1a illustrates that this differential between freight rates mitigates the difference in sales prices (inclusive of ad-valorem trade costs), effectively equalizing the equilibrium demands for transport, and thus, leading to balanced bilateral trade. If we, instead, maintained the traditional symmetric trade cost assumption, while allowing sales prices to vary across countries,

---

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

Figure 1a shows that this symmetry would impose empty containers in the backhaul transport market that are inconsistent with balanced trade. This highlights an import result of the theoretical model, which states that actual trades are only balanced when freight rates are free to endogenously adjust to the demand imbalances and are allowed to be asymmetric between two trading countries.

In contrast, Figure 1b demonstrates the unbalanced trade case, where fronthaul demand, D^F, is much larger than backhaul demand, D^B. Given such a large difference in demand stemming from a large sales price variation across countries, each carrier optimizes by choosing asymmetric transport supplies, $Q^l_{ij} \neq Q^l_{ji}$. This, of course, results in imbalanced bilateral trade in the presence of potentially asymmetric freight rates, $f_{ij} \geq f_{ji}$. Differentiating between the balanced and imbalanced trade cases, the equilibrium solutions are presented more formally next.

Case 1: Balanced Trade

For small transport demand imbalances, each carrier's equilibrium supplies of transport for a given round trip between country i and j and the resulting equilibrium transportation rates can be derived as follows[32]:

$$K^l = Q^l_{ij} = Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma N}{2(\sigma N-1)}\frac{\sigma}{\sigma-1}\left(a_{ij}+a_{ji}+\frac{\partial JC(K^l)}{\partial K^l}+p_i\tau_{ij}+p_j\tau_{ji}\right)\right]^{-\sigma} \tag{2.8a}$$

$$f_{ij} = \frac{\sigma N}{2(\sigma N-1)}\left[a_{ij}+a_{ji}+\frac{\partial JC(K^l)}{\partial K^l}+p_j\tau_{ji}\right]+\frac{2-\sigma N}{2(\sigma N-1)}p_i\tau_{ij} \tag{2.8b}$$

$$f_{ji} = \frac{\sigma N}{2(\sigma N-1)}\left[a_{ij}+a_{ji}+\frac{\partial JC(K^l)}{\partial K^l}+p_i\tau_{ij}\right]+\frac{2-\sigma N}{2(\sigma N-1)}p_j\tau_{ji}. \tag{2.8c}$$

---

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

Case 2: Imbalanced Trade

Solving the model when the demands for transport are strongly imbalanced yields the following expressions for each carrier's equilibrium supplies of transport and capacity allocation, as well as the respective equilibrium transportation rates for a given round trip between country i and j:

$$K^l = Q^l_{ij} = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right)\right]^{-\sigma} \tag{2.9a}$$

$$Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma}{\sigma-1}\frac{\sigma N}{\sigma N-1}\left(a_{ji} + p_j\tau_{ji}\right)\right]^{-\sigma} \tag{2.9b}$$

$$f_{ij} = \frac{\sigma N}{\sigma N-1}(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l}) + \frac{1}{\sigma N-1}p_i\tau_{ij} \tag{2.9c}$$

$$f_{ji} = \frac{\sigma N}{\sigma N-1}a_{ji} + \frac{1}{\sigma N}p_j\tau_{ji}. \tag{2.9d}$$

Thus, in the balanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of transport market pair ij facilitating balanced bilateral trade between country i and j is described by equations (2.2) and (2.8a)-(2.8c). In contrast, in the imbalanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of transport market pair ij facilitating imbalanced bilateral trade between country i and j is described by equations (2.2) and (2.9a)-(2.9d). Both equilibrium cases combined exhibit several key features that are present when trade is facilitated by an international transportation industry that is subject to the backhaul problem.

While marginal access costs play a role in the determination of transport supplies and equilibrium freight rates regardless of the demand imbalance facing carriers, the allocation of marginal joint costs is heavily dependent upon this imbalance. That is, in the balanced trade case, equations (2.8a)-(2.8c) show that marginal joint costs matter to the determination of both fronthaul and backhaul equilibrium transport supplies as well as freight rates. In contrast, equations (2.9a)-(2.9d) demonstrate that, in the imbalanced trade case, marginal joint costs only matter to the determination of the equilibrium fronthaul transportation supply and the equilibrium fronthaul freight rate.

Overall, the above system of theoretical equations provides the basis for the empirical work. It describes the transport market equilibrium facilitating bilateral trade between two countries and allows for comparative statics that are commonly done in the trade literature. Some of these comparative statics are highlighted in the following subsection.

Comparative Statics

One of the key results obtained from various estimations of the gravity equation is the dependence of trade on aggregate income and trade costs. As Head and Mayer (2013) point out, standard trade estimations use proxies, such as distance and cultural as well as geographical ties between trading countries to capture trade costs. However, these trade cost proxies have limitations. For example, Limao and Venables (2001) point out that distance is only weakly related to transport costs, while Combes and Lafourcade (2005) show that it fails to correlate with time-varying transport costs. Thus, in the absence of a unit-specific trade cost proxy or in cases where common controls do not correlate with transportation rates, failure to model the endogeneity of international shipping costs may result in biased coefficient estimates. The existence of such a potential bias can be shown with the theoretical model above. As equations (2.8a)-(2.8c) as well as (2.9a)-(2.9d) illustrate, the determination of equilibrium transportation rates partly depends on the determinants of international trade, namely the domestic sales prices. Therefore, unit-specific trade costs captured by international shipping rates cannot be held constant given a change in these sales prices. Instead, the simultaneous change in trade costs leads to a secondary impact on trade that alters the initial response.

Consider, for example, an exogenous shock to country i's domestic sales price. Given equation (2.2), the partial derivative that captures the overall response of trade from country i to country j to a shock in country i's sales price is given by:

$$\frac{\partial q_{ij}}{\partial p_i} = -\sigma \left[\frac{\sigma}{\sigma - 1} (p_i \tau_{ij} + f_{ij}) \right]^{-\sigma - 1} \frac{\sigma}{\sigma - 1} \left[\tau_{ij} + \frac{\partial f_{ij}}{\partial p_i} \right] \tag{2.10}$$

If freight rates are assumed to be exogenous to the system, it must be true that $\frac{\partial f_{ij}}{\partial p_i} = 0$. However, if equations (2.8b) and (2.8c) as well as (2.9c) are considered, it becomes clear that equilibrium freight rates depend on the domestic sales price regardless of the trade imbalance. To derive the specific response of freight rates, I differentiate between the balanced an imbalanced trade scenarios.[33] In the imbalanced trade case, the responses of the fronthaul and backhaul equilibrium freight rates to a shock in country i's sales price are given by:

$$\frac{\partial f_{ij}}{\partial p_i} = \frac{1}{\sigma N - 1} \tau_{ij} > 0 \tag{2.11a}$$

$$\frac{\partial f_{ji}}{\partial p_i} = 0. \tag{2.11b}$$

---

[33] I abstract from knives' edge cases where a change in sales prices causes a switch in the equilibrium from balanced to imbalanced trade or vice versa.

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

$$\frac{\partial f_{ij}}{\partial p_i} = \frac{2-\sigma N}{2\sigma N - 2}\tau_{ij} \tag{2.12a}$$

$$\frac{\partial f_{ji}}{\partial p_i} = \frac{\sigma N}{\sigma N - 1}\tau_{ij} > 0. \tag{2.12b}$$

These derivatives highlight several important findings. First, regardless of whether a balanced or imbalanced trade equilibrium is considered, equations (2.11a) and (2.12a) show that fronthaul freight rates adjust to an increase in the net exporter's sales price. However, the size and direction of the potential bias varies between the balanced and imbalanced trade cases. If $N > 2$, the fronthaul freight rate, in the balanced trade case, decreases in response to the price shock, while the fronthaul freight rate increases in the imbalanced trade case. Intuitively, while an increase in the sales price causes the demand for transport to fall in both cases, carriers exercising market power adjust the fronthaul transport supply differently across the two scenarios. In the imbalanced trade case, carriers are unconstrained concerning their adjustment of transport supply viewing fronthaul and backhaul as separate products. In contrast, in the balanced trade case, carriers are constrained to keep transport supplies symmetric across fronthaul and backhaul markets leading to a smaller supply adjustment. Overall, this derivation shows that as long as carriers hold market power, the common estimate of $\frac{\partial q_{ij}}{\partial p_i}$ clearly depends on the endogenous adjustment of unit-specific trade costs in response to a change in the determinants of trade and may bias traditional gravity estimations.

Second, equations (2.11b) and (2.12b) demonstrate that the backhaul freight rate, in the imbalanced trade case, remains unchanged, whereas the backhaul freight rate, in the balanced trade case, increases in response to a change in country i's sales price.

This result stems from the presence of joint production in the transportation industry. When trade is balanced, fronthaul and backhaul supply are joint products which leads to the integration of fronthaul and backhaul freight rates. Factors that drive a change in the fronthaul market will trigger a response in the backhaul transport market as well. Specifically, since the fronthaul transport supply decreased in the balanced trade case, a shock to the net exporter's domestic sales price must also cause a reduction in the backhaul transport supply, so that trade remains balanced. This reduction in the backhaul transport supply, naturally leads to the increase in the backhaul freight rate given by (2.12b). Since the elasticity of trade with respect to transport costs is negative, this, of course, results in a reduction of trade facilitated in the backhaul market and an unanticipated spillover effect. Therefore, this model, build on a standard trade framework and accounting for the presence of joint production in the international transportation industry, predicts that when trade is balanced, a trade shock pertinent to country i's exports also leads to an adjustments of country i's imports. This result compliments the finding by Deardorff (2014) showing that not only the presence of unit-specific trade costs, but also their cointegration can distort traditional trade theory results.

Empirical Model

Based on the partial equilibrium conditions (2.2) and (2.8a)-(2.8c) as well as (2.9a)-(2.9d), I develop the empirical model to test whether the theoretical simultaneity between trade and transport costs holds in the data. In particular, for any of the given transport market pairs, the estimation is focused on the demand for transport and fronthaul and backhaul pricing relations described by the static partial equilibrium framework. Since the data are quarterly time series observations in three market pairs and the objective of the empirics is to uncover the static long-run equilibrium relations implied by the structural model, the empirical specifications allow for the use of time series techniques to estimate the static long-run system of equations. In particular, I employ panel cointegration methods to estimate the structural equations underlying the theoretical long-run partial equilibrium model. Indeed, as Hamilton (1994) states:

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

First, the demand equation is considered. As equation (2.2) indicates, the demands for transportation in market pair ij are given by the quantity of containerized bilateral trade facilitated between region i and region j and are a function of sales prices, ad-valorem and unit-specific trade costs. Furthermore, the theoretical model suggests that there are no inherent differences between fronthaul and backhaul transport markets concerning the dependence of trade on these determinants. Thus, I estimate the demand for transport via a single equation, where the quantity of transport demanded between any two regions i and j is denoted by q_{ijt}. The cross-sectional dimension of a trade route is indicated by ij, while the time series dimension of the data is given by t. The domestic sales price is denoted p_{it}, whereas unit-specific trade costs are given by the container freight rate, f_{ijt}, that is charged to facilitate trade from region i to region j. Although the theoretical model, due to its partial equilibrium nature, does not indicate aggregate income to be a determinant of international trade, I follow the vast majority of the trade literature that suggests that aggregate income plays a central role in the determination of trade and thus, the international demand for transport. Following standard practice, aggregate income is given by exporter and importer real GDP and denoted by y_{it} and y_{jt}, respectively.

To capture the unobservable characteristics and control for the heterogeneity between trade routes, a transport market specific fixed effect, α_{ij}, is included in the model. This follows the fixed effect specification suggested by Cheng and Wall (2005) and captures time-invariant ad-valorem trade costs.[34] Panel cointegration tests developed by Pedroni et al. (1999) and Pedroni (2004) are used to allow for this heterogeneity across panels and inform about the necessity of market pair specific time trends. Based on the test results, I do not integrate a market pair specific time trend in the empirical model of the demand for transport.

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

$$q_{ijt} = \alpha_{ij} + \beta_1 f_{ijt} + \beta_2 p_{it} + \beta_3 y_{it} + \beta_4 y_{jt} + \sum_{s=-S}^{S} \Theta^{ij} \Delta x_{ijt+s} + \epsilon_{ijt}, \tag{2.13}$$

where all variables are in logged form, S indicates the maximum number of lags and leads included in the model and the error term is denoted by ϵ_{ijt}. The cointegration relation and coefficients of interest are described by β_1-β_4. Accurately estimating the cointegration

---

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

relation underlying the demand equation renders the residual stationary and implies that any variation from this long-run static equilibrium relationship is only temporary.[35]

To complete the empirical model and demonstrate the simultaneity between trade and transportation, I develop the empirical specifications of the theoretical pricing relations, as suggested by equations (2.8b) and (2.8c) as well as (2.9c) and (2.9d), next. Following the theoretical model, two equilibrium pricing relations distinguishing between fronthaul and backhaul transport markets are considered. The left-hand side variables are given by the international container freight rates, f_{ijt} and f_{jit}. These unit-specific trade costs are each modeled as a function of the respective number of carriers, as well as access and marginal joint costs. The number of carriers competing in market pair ij is captured via this market pair's cumulative shipping capacity, sc_{ijt}. Access costs are controlled for via bunker fuel prices, denoted by bfp_{ijt}. While it is expected that an increase in the price of bunker fuel raises access cost and thus, increases the equilibrium freight rates, an increase in market shipping capacity is associated with intensified competition that diminishes market power and is, thus, expected to lead to a reduction of international freight rates.

Lastly, I specify a proxy for marginal joint costs. As equations (2.8b) and (2.9c) demonstrate, marginal joint costs are a determinant of fronthaul freight rates regardless of the trade imbalance. However, equations (2.8c) and (2.9d) illustrate that the dependence of the backhaul freight rate on marginal joint costs varies between the balanced and imbalanced trade equilibrium scenarios. To capture this switching dependence of the

---

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

backhaul freight rate and control for marginal joint costs, the relative trade imbalance, δ_{ijt}, is integrated in the fronthaul and backhaul empirical pricing relations. Careful consideration of the theoretical model suggests that an increase of the trade imbalance is associated with an increased allocation of marginal joint costs towards the fronthaul transport market. That is, fronthaul freight rates are expected to increase, given a rise of the trade imbalance. In contrast, this reallocation of marginal joint costs away from the backhaul transport market, caused by an increase in the trade imbalance, is associated with a reduction in the backhaul freight rate which no longer covers the reallocated portion.

Again, market pair specific fixed effects to account for the heterogeneity across market pairs and lead and lagged terms of the first differenced right hand side variables, denoted by vector Δz_{ijt}, to control for the endogenous feedback effects are incorporated. The cointegration tests reveal that neither of the long-run equilibrium pricing relations include a market pair specific time trend. Motivated by the theoretical pricing relations (2.8b) and (2.8c) as well as (2.9c) and (2.9d), this leads to the following empirical pricing relation specifications;

$$f_{ijt} = \alpha_{ij} + \gamma_1^{ij} sc_{ijt} + \gamma_2^{ij} bfp_{ijt} + \gamma_3^{ij} \delta_{ijt} + \sum_{s=-S}^{S} \Phi^{ij} \Delta z_{ijt+s} + \nu_{ijt}, \tag{2.14a}$$

$$f_{jit} = \alpha_{ji} + \gamma_1^{ji} sc_{jit} + \gamma_2^{ji} bfp_{jit} + \gamma_3^{ji} \delta_{jit} + \sum_{s=-S}^{S} \Phi^{ji} \Delta z_{jit+s} + \nu_{jit}, \tag{2.14b}$$

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

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

Data

The data that are used to estimate the parameters of the empirical model have been obtained from various sources. Gross Domestic Product and Consumer Price Index (CPI) data to control for aggregate income and domestic sales prices for the U.S., the Euro-Area and several Asian countries have been obtained from the *OECD Main Economic Indicators database*. Since the cross-sectional dimension considers trade at supranational levels (except for the U.S.), Asian GDP is controlled for via the cumulative GDP of Japan, South Korea, India and Indonesia, while the Asian sales price is controlled for via the average CPI of Japan, South Korea, India, Indonesia, and China. The data on regional shipping capacity have been obtained from the *United Nations Conference on Trade and Development (UNCTAD)* database. Market access costs in the Trans-Pacific and Trans-

Atlantic markets are given by the bunker fuel prices in Los Angeles and Philadelphia, respectively, and have been obtained from the *Shipping Intelligence Network*.[36] Data on the left-hand side variables, containerized cargo flow and regional freight rates have been obtained from *Drewry* and *Containerisation International* via the annual reports by UNCTAD, Secretariat (2014), respectively. The majority of the data are observed at quarterly or annual frequencies and span a time frame from the fourth quarter of 1995 to the fourth quarter of 2009.[37] While all variables used in the estimation of the empirical model are seasonally adjusted and in logged form[38], the seasonally unadjusted level data on these variables are summarized in Tables 1 and 2.

In accordance with the theoretical model, the data have been categorized into fronthaul and backhaul transport markets between the various ij market pairs. These market pairs include the *Trans-Pacific Market* which is defined as the container cargo flow between the U.S. and Asia, the *Trans-Atlantic Market* defined as the container cargo flow between the U.S. and EU, and the *Asia-EU Market* including container trade flows between these two regions. The mean values of container cargo flow and freight rates, listed in Table 1, indicate large trade imbalances and freight rate differentials in the Trans-Pacific as well as Asia-EU market. The Trans-Atlantic market, however, exhibits less distinguished imbalances, on average.

Figures 2a-2f provide additional evidence in support of these initial observations. The figures depict the unadjusted freight rates and containerized trade flows for each transport market pair. Imbalances and differentials, present in the Trans-Pacific and

---

[36] Bunker fuel prices for the Asia-EU market were unobtainable. Thus, I have chosen for these prices to be equal to the average between the available two measures. This, however, introduces artificial cross-sectional dependencies that, if adjusted, destroy all variation of this measure.

[37] Market shipping capacity data is only available at annual frequency and has been linearly interpolated to quarterly frequency.

[38] Seasonal adjustments have been performed via the X11 routine. This standard procedure recognizes linear interpolation and leaves the interpolated variables unchanged.

TABLE 1. Summary Statistics - Trade and Unit-specific Trade Costs

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

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

Asia-EU market pairs, are large with a clearly defined net exporting and net importing region. That is, the Trans-Pacific market pair between the U.S. and Asia, exhibited by Figures 2a and 2b, clearly shows that the trade route from Asia to the U.S. constitutes the fronthaul transport market, ij, for the majority of the sample period, while the route from the U.S. to Asia constitutes the backhaul, ji, for the majority of the sample. Similarly, the market pair between Asia and the EU, which is depicted in Figures 2c and 2d, has a clearly defined fronthaul transport market, ij, where trade is facilitated from Asia to the EU and a subsequent backhaul, ji, where trade is facilitated from the EU to Asia. The freight rate differentials in these markets mirror the clear distinction between fronthaul and backhaul trade flows.

In contrast, Figures 2e and 2f show that the Trans-Atlantic market pair exhibits switching trade imbalances that roughly coincide with switching freight rate differentials.

TABLE 2. Summary Statistics - Trade and Freight Rate Determinants

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Regional GDP (trillion U.S.$)					
U.S. GDP	57	13.21	1.454	10.41	15.17
Euro-Area (19) GDP	57	11.05	0.914	9.416	12.51
Asia GDP	55	9.696	1.410	7.952	12.31
Regional CPI (2010=100)					
U.S. CPI	57	84.36	9.024	70.40	100.6
Euro-Area (19) CPI	57	86.51	7.423	75.20	98.90
Asia CPI	57	76.92	10.42	59.46	97.40
Regional Shipping Capacity (1000 DWT)					
Shipping Capacity - Transpacific market	57	20,621	4,812	13,836	34,151
Shipping Capacity - Asia-EU market	57	42,846	14,696	23,065	77,584
Shipping Capacity - Trans-Atlantic market	57	29,243	9,705	14,948	50,082
Bunker Fuel Prices ($ per ton)					
Bunker Fuel Price West Coast (Los Angeles)	57	212.8	141.4	60.85	686.6
Bunker Fuel Price East Coast (Philadelphia)	57	210.5	135.8	61.88	659
Containerized Trade Imbalance					
Imbalance - Trans-Pacific Market	56	-0.523	0.141	-0.977	-0.346
Imbalance - Asia-EU Market	48	-0.574	0.0973	-0.733	-0.405
Imbalance - Trans-Atlantic Market	56	-0.808	0.112	-1.000	-0.604

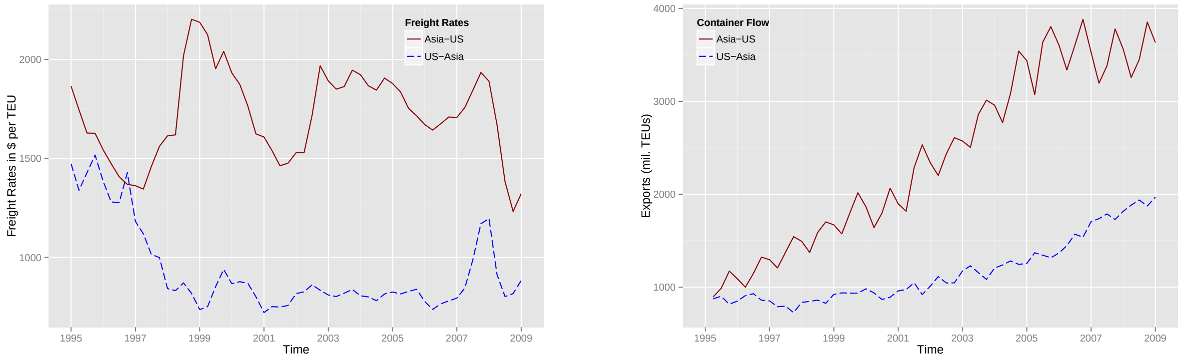
Sources: GDP & CPI - *OECD*, Bunker Fuel Prices - *Shipping Intelligence Network*, Market Shipping Capacity - *UNCTAD* and Trade Imbalance - *Drewry*

In particular, the figures reveal that initial observations point roughly balanced bilateral trade between the U.S. and EU, where fronthaul and backhaul transport markets are not clearly defined until the second quarter of 1997. In line with the theoretical model, the freight rate differential is initially relatively small and declines over this time period. In contrast, observations from the second quarter of 1997 until the second quarter of 2007 exhibit a much larger trade imbalance, where westbound EU to U.S. trade is clearly defined as the fronthaul transport market. During this period, freight rates adjust to this stark trade imbalance. As the theory predicts, the freight rate charged to facilitate westbound EU to U.S. trade becomes much larger than the backhaul freight rate charged on eastbound U.S. to EU trade reflecting the reallocation of marginal joint costs towards the fronthaul transport market. At the end of the sample period, however, the trade imbalance switches and the eastbound U.S. to EU trade becomes the fronthaul transport market. Freight rates adjust to this changing trade pattern, so that the freight charged on eastbound U.S. to EU trade becomes the larger fronthaul freight rate by the end of the sample. These observations warrant the careful empirical model specification that describes the pricing relations in terms of fronthaul, ij, and backhaul, ji, transport markets, rather than directional east and west bound trade flows that potentially disturb the fronthaul and backhaul distinction.

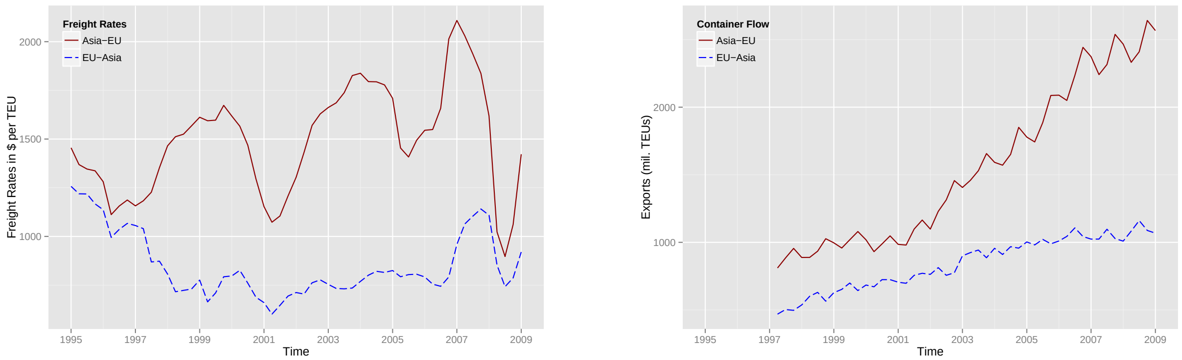
The remaining data consists of time series observations for the variables that are used as aggregate income shifters, sales price controls and shipping cost factors in the estimation. Table 2 presents the summary statistics on the GDP, CPI, market shipping capacities, bunker fuel prices and trade imbalance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

Results

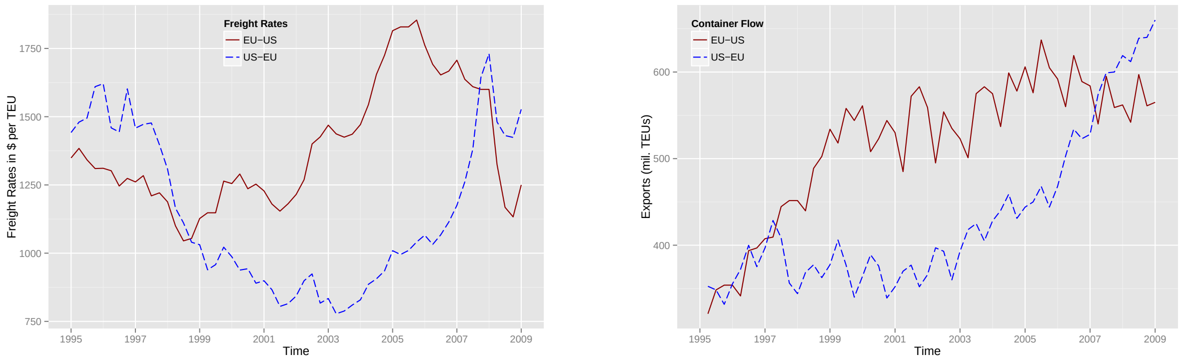
In this section, the empirical results are presented. First, I apply multiple panel unit root tests to all of the individual time series used in the estimation. Several of these tests point to non-stationarity of various time series in the data and integration of order one. Given the non-stationarity, the empirical analysis then proceeds with tests for panel cointegration developed by Pedroni et al. (1999) and Pedroni (2004). The tests produce supporting evidence of the existence of cointegration. Based on these results, the cointegration relations are estimated and the structural demand and pricing relationships of the container shipping industry that govern the long-run equilibrium of containerized trade are obtained. These estimates point to the simultaneity between trade and unit-specific trade costs. The estimation is carried out via the group-mean Panel FMOLS



(a) Trans-Pacific Freight Rates (b) Trans-Pacific Cargo Flows



(c) Trans-Pacific Freight Rates (d) Trans-Pacific Cargo Flows



(e) Trans-Pacific Freight Rates (f) Trans-Pacific Cargo Flows

FIGURE 2. Trade Imbalances and Freight Rate Differentials

and DOLS estimators developed by Pedroni (2000) and Pedroni (2001), respectively. I conclude this section with a discussion and interpretation of the estimated cointegration relations and use the specific estimates to simulate the long-run equilibrium impact of several permanent shocks, such as the reduction of carrier market power, on trade and freight rates distinguishing between fronthaul and backhaul transport markets.

Unit root tests

Several panel unit root tests on each of the time series that are incorporated in the estimation of the structural model of trade and transportation have been performed. The panel unit root tests employed, include the Levin-Lin-Chu (LLC) test developed by Levin et al. (2002) as well as Phillips-Perron (PP) and augmented Dickey-Fuller (ADF) tests developed by Choi (2001).[39] There are a number of tests available to examine the existence of panel unit roots. The specific tests chosen for this analysis are built on assumptions that best fit the data employed in this study. Some of these assumptions that are common among these tests, include the fact that they are devised for a finite number of cross-sections as well as the ability to allow for cross-section specific fixed effects and time trends.[40]

The results of the panel unit root tests are given in Table 3 and are presented for the levels as well as first differences of each time series. While the adjusted t-statistic is reported for the LLC test, the Z-statistic, as recommended by Choi (2001), is reported for the ADF and PP tests. After careful graphical examination of each level time series,

---

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

[40] Other commonalities include the fact that all three tests maintain the null hypothesis that the time series exhibits a panel unit root. However, the alternative hypotheses vary across tests. That is, for a finite number of cross-sections the alternative hypothesis of the PP and ADF tests holds that the time series of at least one cross-section does not exhibit a unit root. In contrast, the LLC test operates under the alternative hypothesis that none of the cross-sections exhibit a unit root.

a time trend has been included in the regression equations of the tests for the transport quantity demanded, exporter/importer GDP, CPI, shipping capacity, and bunker fuel prices. Considering the panel unit root tests on the differenced data no time trends were included in the regression equations. The issue of lag selection has been addressed with the Hannan-Quinn Information Criterion (HQIC). Furthermore, none of the time series were demeaned prior to any of the tests.[41]

As the test-statistics reported in Table 3 suggest, there is strong evidence that at least two of the time series in the demand and each of the pricing relations are integrated of order one. On the demand side, the majority of the tests show that the null hypothesis of a panel unit root for the level of the transport quantity demanded, CPI and exporter/importer GDP cannot be rejected. In contrast, test results on freight rates are mixed. Although the PP test fails to reject the null hypothesis of a panel unit root at the 1% significance level, the LLC and ADF test reject the existence of a panel unit root at the 1% level. Identical tests applied to the first difference of the non-stationary variables strongly reject the null hypothesis of a panel unit root suggesting that the transport quantity demanded, CPI and exporter/importer GDP are, in fact, integrated of order one, while freight rates may be integrated of order one.

Concerning the pricing relations, all of the tests provide strong evidence that the level of market shipping capacity and the trade imbalance reflect a panel unit root, while the evidence of a panel unit root concerning freight rates is rather mixed. That is, for the fronthaul freight rate the Fisher-type PP test fails to reject the null hypothesis of a panel

---

[41] Demeaning panel data is used to control for cross-sectional dependencies. However, exporter/importer GDPs are identical across some of the three market pairs. For example, the U.S. is an exporter to Asia in the Trans-Pacific market as well as Europe in the Trans-Atlantic market. This creates cross-sectional dependencies concerning exporter GDP. Furthermore, bunker fuel prices for the Asia-EU market pair are generated by averaging the available price measures for the other two market pairs in the panel. Thus, exact cross-sectional dependence for these time series is an artifact of the data generation, and demeaning these data distorts important variation. The empirical results of the panel unit root tests are generally robust to demeaning the remaining time series and are available upon request.

TABLE 3. Panel Unit Root Tests

	Levels			**1st Difference**		
		Fisher-type			Fisher-type	
	LLC	DF	PP	LLC	DF	PP
Demand						
Quantity (q_{ij})	-2.68***	2.00	2.11	-13.76***	-5.78***	-14.23***
Freight Rate (f_{ij})	-2.46***	-3.58***	-1.18	-6.92***	-7.89***	-8.60***
Sales Price (p_i)	-0.54	-1.84**	0.34	-7.23***	-6.51***	-10.31***
Exp./Imp. GDP (y_i/y_j)	1.54	0.85	4.07	-5.74***	-4.09***	-7.19***
Pricing Relations						
FH Freight Rate (f_{fh})	-3.54***	-2.59***	-0.89	-6.98***	-5.16***	-7.75***
BH Freight Rate (f_{bh})	-1.32*	-2.37***	-1.47*	-8.46***	-6.42***	-7.95***
Shipping Capacity (sc)	1.82	1.62	2.31	0.61	-1.63*	-1.55 *
Bunker Fuel Price (bfp)	-4.21***	-3.38***	-1.42*	-5.41***	-4.90***	-10.09***
Trade Imbalance (δ)	0.28	0.32	0.18	-9.88***	-5.87***	-10.53***

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

unit root at any significance level, while both the LLC and Fisher-type ADF test reject the null at the 1% level. Similarly, for the backhaul freight rate, both the LLC and Fisher-type PP tests fail to reject the null hypothesis of the presence of a panel unit root at the 5% significance level, whereas the Fisher-type ADF test rejects the null at the 1% level. Contrary to these mixed findings, with exception of market shipping capacity, all of the tests suggest that the first difference of all variables is stationary at the 1% significance level. Even for market shipping capacity, both of the Fisher-type tests reject the null of a panel unit root at the 10% level. Based on these tests on the pricing relations variables, I conclude that market shipping capacity and the trade imbalance are also integrated of order one, while fronthaul and backhaul freight rates may be integrated of order one.

Given the fact that all variables are integrated of order one or less and that at least two variables of the demand and each pricing relation are integrated of order one, the empirical analysis continues with the panel cointegration tests developed by Pedroni et al. (1999) and Pedroni (2004).[42] That is, I have found evidence of panel unit root processes of order one, which point to the possible use of cointegration techniques that allow for super-consistency and unbiased coefficient estimates, despite potential concerns of endogeneity or non-stationarity of the individual data series. Specifically, I take advantage of the information contained within the cointegration equation and estimate the long-run structural relations projected by the static equilibrium model previously developed.

Cointegration Tests

To allow for the heterogeneity across transport markets, the panel cointegration tests are based on Pedroni's (1999, 2004) seven test-statistics and critical values. Due to varying small sample properties, all test statistics are reported. Since the panel employed for the demand and pricing relations estimations includes only a short cross-sectional dimension and a medium length time dimension, rejection of the null hypothesis of no cointegration of any test, gives evidence for the existence of cointegration relations. Consistent with the panel unit root tests, none of the time series embedded in the empirical model are demeaned. However, I do allow for cross-section specific fixed effects and use the tests to determine the potential inclusion of time trends present in the cointegration relations.

The results of these tests are presented in Table 4 and provide supporting evidence of the existence of cointegration relations between trade, trade costs, trade prices and aggregate income on the demand side and trade costs, the trade imbalance, as well as market power and shipping cost factors on the supply side. In particular, on the demand side, five out of the seven tests excluding a time trend reject the null hypothesis of no panel cointegration at the 5% level, while the Panel ρ-test rejects the null at the 10% level.

---

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

This rejection rate declines drastically once a time trend is included. I interpret these findings as strong evidence for the existence of a trend exclusive cointegration relation that governs international trade, and thus, the demand for transport, as a function of unit-specific trade costs, the domestic sales price and exporter as well as importer aggregate incomes.

Concerning the pricing relations, I test for the existence of cointegration differentiating between fronthaul and backhaul transport markets. While the cointegration tests excluding a time trend provide only limited evidence of a cointegration relation concerning the fronthaul pricing relation (only the Panel ν-statistic rejects the null of no cointegration at the 10% level), the existence of a time trend exclusive cointegration relation governing the backhaul pricing relation is strongly supported by six out of seven tests that reject the null in favor of the alternative hypothesis at either the 5% or 10% significance level. In contrast, the evidence concerning the existence of time trend inclusive cointegration relations is less convincing for both pricing relations and thus, estimations are carried out without a time trend.

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

Cointegration Relations Estimation

As noted earlier, the existence of cointegration among the unit root processes leads to super consistency of the OLS estimates. However, as several studies have pointed out, the endogeneity takes hold in a second order bias that can have a significant influence,

TABLE 4. Panel Cointegration Tests

Panel Cointegration Statistics	Demand		Fronthaul Pricing		Backhaul Pricing	
Panel ν-statistic	2.02**	0.83	1.37*	0.37	2.26**	1.39*
Panel ρ-statistic	-1.59*	-0.78	-0.54	0.12	-1.40*	-1.00
Panel pp-statistic	-2.02**	-1.57*	-0.77	-0.31	-1.68**	-1.74**
Panel adf-statistic	-1.88**	-1.78**	-0.89	-0.49	-1.44*	-1.47*
Group ρ-statistic	-0.78	0.8	0.07	0.70	-0.79	-0.42
Group pp-statistic	-1.83**	-1.08	-0.55	-0.02	-1.55*	-1.50*
Group adf-statistic	-2.16**	-1.88**	-0.83	-0.30	-1.42*	-1.40*
Trend	no	yes	no	yes	no	yes

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

despite this super-consistency. Several estimators have been proposed to address this second-order bias and obtain unbiased estimates of the cointegration relation of interest. Among these estimators are various versions of the Fully Modified OLS and Dynamic OLS estimators. Several studies have used Monte Carlo simulations to better understand the small sample properties of these estimators and have drawn comparison across them. Kao and Chiang (1999), for example, show that the 'within-dimension' DOLS estimator outperforms both the OLS as well as the 'within-dimension' FMOLS estimators, and can be applied for both homogeneous and heterogeneous panels. In response to these findings, Pedroni (2000) develops a 'between-dimension' FMOLS estimator and demonstrates that it performs well for small samples. In line with the literature and to provide a more complete analysis, I employ and report the results of the group-mean Panel DOLS estimator developed by Pedroni (2001) as well as the group-mean Panel FMOLS estimator developed by Pedroni (2000).

Guided by the empirical model and following the cointegration tests, the estimation of the cointegration relations includes panel specific fixed effects, but excludes market specific time trends. The results of the group-mean panel DOLS estimator are given in Table 5, while the results of the group-mean panel FMOLS estimator are presented in Table 6. Generally, I find statistically significant coefficient estimates for all cointegration relations. In fact, across both estimators all but two coefficient estimates are statistically significant at either the 1% or 5% significance level and all estimates match the expected signs. That is, on the demand side, unit specific trade costs as well as domestic sales prices exhibit a negative correlation with the volume of trade, while aggregate incomes exhibit a positive correlation with international trade. Concerning the determination of the long-run equilibrium freight rates, despite the variation in coefficient magnitude, both fronthaul and backhaul pricing relations show that a persistent rise in access costs, due to increases in bunker fuel prices, leads to permanent increases in freight rates. In contrast, a permanent increase in competition via larger market shipping capacity is associated with a long-run decline in fronthaul and backhaul freight rates. Furthermore, both estimators illustrate that persistent changes in joint costs have a varying effect on fronthaul and backhaul transport rates.

Considering the estimated demand relation, given by column (1) in Tables 5 and 6, in more detail, I find consistency of coefficient estimates across the DOLS and FMOLS estimator. While the coefficient on freight rates turns up insignificant for the DOLS estimator, its magnitude of -0.044 is very similar to the FMOLS estimate of -0.058 which is significant at the 1% level. Focusing on the highly statistically significant estimate of the FMOLS estimator, the demand cointegration relation suggests that in the long-run, on average, a 1% permanent increase in freight rates permanently reduces trade by 0.058%. This very inelastic response of containerized trade to a change in unit-specific trade costs appears reasonable when considering the fact that container freight rates are relatively small compared to the total cargo value of a container.[43] Similar to this finding, the DOLS and FMOLS estimators also show an inelastic long-run response of international trade to a change in sales prices. Coefficient estimates range from -0.340 (FMOLS) to -0.597 (DOLS) and are both statistically significant at the 5% level. These findings imply that a persistent 1% increase of domestic goods prices leads to a 0.340%-0.597% long-run reduction of international containerized exports.

Additionally, the results show that long-run increases in economic mass, measured by the exporter's and importer's GDP, drive international trade. This finding is consistent across the DOLS and FMOLS estimators and statistically significant at the 1% level. Specifically, the DOLS estimator finds that a permanent 1% increase in exporter GDP raises containerized trade by 0.927% in the long-run, while the same persistent increase in importer GDP permanently raises trade by 1.189% in the long-run. Coefficient estimates of the FMOLS estimator suggest that a persistent 1% rise in exporter GDP leads to a permanent 0.632% increase in trade, whereas a permanent 1% increase in importer GDP raises containerized trade by 1.326% in the long-run. One common prediction of the gravity model (see, for example, Anderson and van Wincoop, 2003) is that the effects of exporter and importer economic mass on trade are theoretically equal to unity. In column (2) of Tables 5 and 6, I test this hypothesis and find strong evidence in support of it. Specifically, based on the DOLS coefficient estimates, I fail to reject the null hypothesis that the long-run equilibrium effects of importer and exporter GDP on containerized international trade are unit elastic at any significance level. The same is true for the FMOLS estimates at the 1% significance level.

---

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

TABLE 5. Cointegration Relations - Group-mean Panel Dynamic OLS Estimator

	(1)	(2)	(3)	(4)	(5)
	Demand		FH Pricing	BH Pricing	
Variables	q_{ij}	q_{ij}	f_{fh}	f_{bh}	f_{bh}
Freight Rate (f_{ij})	-0.044	-0.044	-	-	-
	(-1.350)	(-1.350)			
Sales Price (p_i)	-0.597**	-0.597**	-	-	-
	(-2.374)	(-2.374)			
Exporter GDP (y_i)	0.927***	0.927	-	-	-
	(3.544)	(-0.280)			
Importer GDP (y_j)	1.189***	1.189	-	-	-
	(4.874)	(0.775)			
Shipping Capacity (sc)	-	-	-0.733***	-0.425***	-0.425***
			(-4.667)	(-4.405)	(3.201)
Bunker Fuel Price (bfp)	-	-	0.449***	0.121***	0.121***
			(5.543)	(2.657)	(-7.154)
Trade Imbalance (imb)	-	-	0.352**	-0.307***	-0.307***
			(2.322)	(-3.515)	(-7.550)
Lags and Leads	1	1	1	1	1
Panels	6	6	3	3	3
Observations	320	320	160	160	160
Coefficient Hypothesis	[0, 0, 0, 0]	[0, 0, 1, 1]	[0, 0, 0]	[0, 0, 0]	[-0.73, 0.45, -0.35]

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

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

Observing these differences in magnitude across coefficient estimates, the estimation of the backhaul pricing relation testing the hypotheses of equality across fronthaul and backhaul coefficient estimates is repeated. The results are given in column (5) of Tables 5 and 6 and reveal that the differences in fronthaul and backhaul coefficient estimates are, indeed, statistically significant for all variables. Concerning the coefficient estimates on market shipping capacity, this finding implies that an increase in competition among carriers has a statistically significantly smaller effect on the freight rates charged in backhaul compared to fronthaul transport markets. This finding is intuitive. Since backhaul markets are by definition subject to excess capacity, an increase in market shipping capacity should have a smaller effect on transport rates in backhaul markets than in fronthaul markets where capacity allocation is binding and carriers can exercise larger market power in setting fronthaul rates.

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

TABLE 6. Cointegration Relations - Group-mean Panel Fully Modified OLS Estimator

	(1)	(2)	(3)	(4)	(5)
	Demand		FH Pricing	BH Pricing	
Variables	q_{ij}	q_{ij}	f_{fh}	f_{bh}	f_{bh}
Freight Rate (f_{ij})	-0.058**	-0.058**	-	-	-
	(-2.395)	(-2.395)			
Sales Price (p_i)	-0.340**	-0.340**	-	-	-
	(-1.963)	(-1.963)			
Exporter GDP (y_i)	0.632***	0.632**	-	-	-
	(3.397)	(-1.975)			
Importer GDP (y_j)	1.326***	1.326*	-	-	-
	(6.954)	(1.710)			
Shipping Capacity (sc)	-	-	-0.509***	-0.342***	-0.342**
			(-4.413)	(4.369)	(2.120)
Bunker Fuel Prices (bfp)	-	-	0.296***	0.112***	0.112***
			(5.841)	(3.494)	(-5.749)
Trade Imbalance (imb)	-	-	0.140	-0.446***	-0.446***
			(1.404)	(-7.101)	(-9.324)
Panels	6	6	3	3	3
Observations	320	320	160	160	160
Coefficient Hypothesis	[0, 0, 0, 0]	[0, 0, 1, 1]	[0, 0, 0]	[0, 0, 0]	[-0.51, 0.30, -0.14]

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

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

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

Simulation

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

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

TABLE 7. Simulation Results

Variables	Δsc (10%)	Δbfp (-10%)	Δy_i (1%)	Δp_i (10%)
FH Trade (q_{ij})	0.321%	0.195%	0.931%	-5.874%
BH Trade (q_{ji})	0.189%	0.055%	1.187%	-0.083%
FH Freight Rate (f_{ij})	-7.284%	-4.441%	-0.089%	-2.172%
BH Freight Rate (f_{ji})	-4.290%	-1.253%	0.077%	1.894%

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

Next, I consider the effects of a persistent 10% decline in bunker fuel prices in fronthaul and backhaul transport markets. Table 7 reveals that fronthaul freight rates permanently decrease by 4.441%, while backhaul freight rates permanently decline by only 1.253%. The reductions in unit-specific trade costs coincide with a 0.195% and 0.055%

long-run rise in fronthaul and backhaul trade, respectively. Although the estimated long-run effects on trade are rather small, these simulations point to the potential of maritime transit policy to stimulate the growth of international trade.

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

Another simulation that highlights not only this simultaneity between trade and transportation, but also the potential spillover effects deriving from the joint production present in the international liner shipping industry, concerns the long-run effects of a 10% increase in country i's sales price. The naive model of trade, ignoring endogenously adjusting freight rates, predicts that a change in country i's sales price should only affect country i's exports. Expanding the model to account for the simultaneity between trade and transport suggests that the freight rate charged on country i's exports should also adjust to this change in trade, while transport from country j to i remains unaffected. However, as illustrated in Table 7, the change in country i's sales price not only causes an adjustment in country i's exports and trade costs, but also leads to a persistent response of trade and freight rates in the backhaul transport market facilitating trade from country j to country i.

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

Conclusion

Naturally, international trade critically depends on transport markets. The majority of previous models either ignore this dependence or fail to fully capture the unique market defining characteristics present in the international transportation industry. In this study, I carefully integrate trade and transportation. Furthermore, I derive the transport sector recognizing that the international container shipping markets are subject to the key feature of joint production. Given the model, I evaluate the structural relationships by obtaining estimates of cointegration relations present in the data. The results demonstrate the existence of long-run equilibrium relations that govern the simultaneous determination of trade and unit-specific trade costs measured by container freight rates and explain spillover effects across bilateral export and import markets.

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

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

Bridge

Having provided theoretical and empirical evidence of the simultaneity of trade and transportation, I further explore its consequences in the following chapter. In particular, the endogeneity and asymmetry of transport costs in the presence of imbalanced bilateral trade raises the possibility of systematic variation concerning the response of these freight rates to trade and maritime transport policy. Extending the previously derived theoretical model, I investigate the elasticities of trade with respect to carrier costs, in the following chapter. An empirical examination of these elasticities provides supporting evidence for the theoretical model developed in the current chapter.

CHAPTER III

TRADE POLICY OUTCOMES IN THE PRESENCE OF ASYMMETRIC TRANSPORT COSTS:THEORY AND EVIDENCE

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) has initiated 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

---

[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.

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 available 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.

---

[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 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*.

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 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 U.S.-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 U.S.-EU bilateral trade flows relative to all other U.S. trade and differentiates the average treatment effects along various dimension, including U.S. containerized exports and imports, U.S. fronthaul and backhaul transport markets, across balanced and imbalanced bilateral trade flows and across U.S. 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 U.S.-EU containerized backhaul trade, while U.S.-EU trade facilitated in fronthaul transport markets exhibits no statistically significant response.[5] Based on the patterns of U.S. trade, these findings translate into a statistically significant 8.0% reduction of U.S. exports to EU countries and a statistically insignificant effect on U.S. imports. Further differentiation between rather balanced and imbalanced bilateral U.S. 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

---

[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.

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 U.S. containerized exports and imports. Overall, the empirical results presented in this study are the first to provide quantitative evidence concerning

---

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

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.

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],

---

[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).

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 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 U.S. 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, previously granted to the liner shipping conferences in EU trades, led to the termination of the Transatlantic Conference Agreement (TACA). Based on these recent regulations, it is clear that the container shipping industry has lost some of its

---

[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).

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

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 U.S. was the world's largest importer and second largest exporter 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 8 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 U.S., point to large trade imbalances that coincide with sizable average freight rate differentials in these markets.

Figures 2a-2f in Chapter II further suggest that trade imbalances and freight rate differentials are highly correlated and persistent over time. The transpacific market, depicted in Figure 2b, shows large and growing trade imbalances between U.S. imports from Asia and U.S. containerized exports to this region that correspond to growing freight rate differentials in this market, as illustrated by Figure 2a. In contrast, the transatlantic market between the EU and U.S., illustrated by Figure 2f, reveals switching trade imbalances between the two regions that largely coincide with the switching freight rate differentials depicted by Figure 2e.

TABLE 8. 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*

Overall, it is clear that the liner shipping industry plays an integral role in the facilitation of international trade and U.S. 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 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.

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.

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

---

[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 (2001) 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 U.S. imports far outweighed the costs imposed by tariffs.

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 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.

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

---

[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.

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 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).

---

[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.

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 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 U.S. 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.

Theory

The theoretical model developed in this section integrates trade and transportation. The solution to this model is given by an equilibrium in both of 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]

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 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

---

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

function

$$U_j = q_{0j} + \sum_{i=1}^{M} q_{ij}^{(\sigma-1)/\sigma}, \tag{3.1}$$

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

$$Y_j = q_{0j} + \sum_{i=1}^{M} p_{ij}q_{ij}, \tag{3.2}$$

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;

$$q_{ij} = \left[\frac{\sigma}{\sigma-1}(p_i\tau_{ij} + f_{ij})\right]^{-\sigma}. \tag{3.3}$$

Supply of Transport

This expression for the demand of transport, given by equation (3.3), 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 the 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

---

[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.

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 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:

$$C^l = a_{ij}Q^l_{ij} + a_{ji}Q^l_{ji} + JC(K^l) \ \forall l = 1, ..., N \ and \ i, j = 1, ..., M, \ i \neq j. \tag{3.4}$$

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

$$
\begin{aligned}
&\max_{K^l, Q^l_{ij}, Q^l_{ji}} \Pi^l = f_{ij} Q^l_{ij} + f_{ji} Q^l_{ji} - C^l \quad \forall l = 1, ..., N \text{ and } i, j = 1, ..., M, \ i \neq j \\
&\text{subject to } K^l \geq Q^l_{ij}, \ K^l \geq Q^l_{ji}.
\end{aligned}
\tag{3.5}
$$

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;

$$\frac{\partial \Pi^l}{\partial Q^l_{ij}} = f_{ij} + Q^l_{ij} \frac{\partial f_{ij}}{\partial Q^l_{ij}} - a_{ij} - \lambda_1 \leq 0 \quad \text{with} = \text{if } Q^l_{ij} > 0 \quad \forall l = 1, ..., N \tag{3.6a}$$

$$\frac{\partial \Pi^l}{\partial Q^l_{ji}} = f_{ji} + Q^l_{ji} \frac{\partial f_{ji}}{\partial Q^l_{ji}} - a_{ji} - \lambda_2 \leq 0 \quad \text{with} = \text{if } Q^l_{ji} > 0 \quad \forall l = 1, ..., N \tag{3.6b}$$

$$-\frac{\partial JC(K^l)}{\partial K^l} + \lambda_1 + \lambda_2 \leq 0 \quad \text{with} = \text{if } K^l > 0 \quad \forall l = 1, ..., N \tag{3.6c}$$

$$K^l \geq Q^l_{ij}, \quad \lambda_1 \geq 0, \quad (K^l - Q^l_{ij})\lambda_1 = 0 \tag{3.6d}$$

$$K^l \geq Q^l_{ji}, \quad \lambda_2 \geq 0, \quad (K^l - Q^l_{ji})\lambda_2 = 0. \tag{3.6e}$$

The first-order conditions with respect to transport supplies, given by equations (3.6a) and (3.6b), 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 (3.6c) 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;

$$q_{ij} = \sum_{l=1}^{N} Q^l_{ij} \tag{3.7a}$$

$$q_{ji} = \sum_{l=1}^{N} Q^l_{ji}. \tag{3.7b}$$

Combining the demand for transport given by equation (3.3), the first-order and Kuhn-Tucker conditions given by (3.6a)-(3.6e) and the market clearing conditions represented by equations (3.7a) and (3.7b), 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 (3.3), this demand imbalance can be represented and rewritten as follows;

$$q_{ij} \geq q_{ji} \implies p_j\tau_{ji} - p_i\tau_{ij} \geq (f_{ij} - f_{ji}), \tag{3.8}$$

As equation (3.8) 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:

$$p_j\tau_{ji} - p_i\tau_{ij} \in \left(a_{ij} - a_{ji} - \frac{\partial JC(K^l)}{\partial K^l}\ ;\ a_{ij} - a_{ji} + \frac{\partial JC(K^l)}{\partial K^l}\right), \tag{3.9}$$

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]

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

---

[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.

transportation rates can be derived as follows:

$$K^l = Q^l_{ij} = Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma N}{2(\sigma N - 1)}\frac{\sigma}{\sigma - 1}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij} + p_j\tau_{ji}\right)\right]^{-\sigma} \tag{3.10a}$$

$$f_{ij} = \frac{\sigma N}{2(\sigma N - 1)}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_j\tau_{ji}\right) + \frac{2 - \sigma N}{2(\sigma N - 1)}p_i\tau_{ij} \tag{3.10b}$$

$$f_{ji} = \frac{\sigma N}{2(\sigma N - 1)}\left(a_{ij} + a_{ji} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right) + \frac{2 - \sigma N}{2(\sigma N - 1)}p_j\tau_{ji}. \tag{3.10c}$$

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 the resulting bilateral equilibrium transportation rates:

$$K^l = Q^l_{ij} = \frac{1}{N}\left[\frac{\sigma}{\sigma - 1}\frac{\sigma N}{\sigma N - 1}\left(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l} + p_i\tau_{ij}\right)\right]^{-\sigma} \tag{3.11a}$$

$$Q^l_{ji} = \frac{1}{N}\left[\frac{\sigma}{\sigma - 1}\frac{\sigma N}{\sigma N - 1}\left(a_{ji} + p_j\tau_{ji}\right)\right]^{-\sigma} \tag{3.11b}$$

$$f_{ij} = \frac{\sigma N}{\sigma N - 1}\left(a_{ij} + \frac{\partial JC(K^l)}{\partial K^l}\right) + \frac{1}{\sigma N - 1}p_i\tau_{ij} \tag{3.11c}$$

$$f_{ji} = \frac{\sigma N}{\sigma N - 1}a_{ji} + \frac{1}{\sigma N - 1}p_j\tau_{ji}. \tag{3.11d}$$

Discussion

Thus, in the balanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of transport market pair ij facilitating balanced bilateral trade between countries i and j is described by equations (3.3) and (3.10a)-(3.10c). In contrast, in the imbalanced trade case, the partial equilibrium, $\left(q_{ij}, q_{ji}, K^l, Q^l_{ij}, Q^l_{ji}, f_{ij}, f_{ji}\right)$, of transport market pair ij

facilitating imbalanced bilateral trade between countries i and j is described by equations (3.3) and (3.11a)-(3.11d). 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.

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

$$\frac{\partial q_{ij}}{\partial a_{ij}}\frac{a_{ij}}{q_{ij}} = -\sigma\frac{a_{ij}}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} < 0 \text{ if } Q_{ij} = Q_{ji}, \tag{3.12}$$

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

$$\frac{\partial q_{ij}}{\partial a_{ij}}\frac{a_{ij}}{q_{ij}} = -\sigma\frac{a_{ij}}{(p_i\tau_{ij}+f_{ij})}\frac{\partial f_{ij}}{\partial a_{ij}} = \begin{cases} -\sigma\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}+JC'} < 0 & \text{if } Q_{ij} > Q_{ji} \quad (fronthaul) \\ -\sigma\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}} < 0 & \text{if } Q_{ij} < Q_{ji} \quad (backhaul) \end{cases} . \tag{3.13}$$

Equations (3.12) and (3.13) illustrate one of the key points of this study. When trade is imbalanced, equation (3.13) 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 A)*

In contrast, when trade is balanced, equation (3.12) 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 (3.9), 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 (3.13), 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 represent a larger barrier to international trade for bulky and heavy goods, such as metals or assembled furniture, trade in these

---

[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.

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 A)*

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:

$$\frac{\partial q_{ij}}{\partial JC'}\frac{JC'}{q_{ij}} = -\sigma\frac{JC'}{p_i\tau_{ij}+p_j\tau_{ji}+a_{ij}+a_{ji}+JC'} \text{ if } Q_{ij}=Q_{ji}, \tag{3.14}$$

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

$$\frac{\partial q_{ij}}{\partial JC'}\frac{JC'}{q_{ij}} = -\sigma\frac{JC'}{(p_i\tau_{ij}+f_{ij})}\frac{\partial f_{ij}}{\partial JC'} = \begin{cases} -\sigma\frac{JC'}{p_i\tau_{ij}+a_{ij}+JC'} & \text{if } Q_{ij}>Q_{ji} \quad \text{(fronthaul)} \\ 0 & \text{if } Q_{ij}<Q_{ji} \quad \text{(backhaul).} \end{cases} \tag{3.15}$$

The interpretation of these results is very similar to the 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 (3.15) 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 the 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, U.S. containerized trade. While U.S. containerized exports typically represent a backhaul to a carrier's round trip in recent decades, U.S. containerized imports typically represent a fronthaul. The theoretical results suggest that trade policy, such as the *StrongPorts*[26] initiative by the Maritime Administration

---

[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 B.

[26] The basic goal of the 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

or the Trade Facilitation Agreement[27] by the WTO, will lead to very different outcomes concerning U.S. containerized exports and imports. In fact, a reduction in marginal access costs that applies to both U.S. containerized exports and imports is expected to have a larger effect on U.S. exports than imports, while a reduction in marginal joint costs is expected to mainly affect U.S. containerized imports.

Empirical Model

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

---

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.

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 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 various 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.

---

[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.

[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.

(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 U.S.-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 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 have caused a few issues to properly identify the resulting treatment effects on U.S.-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

---

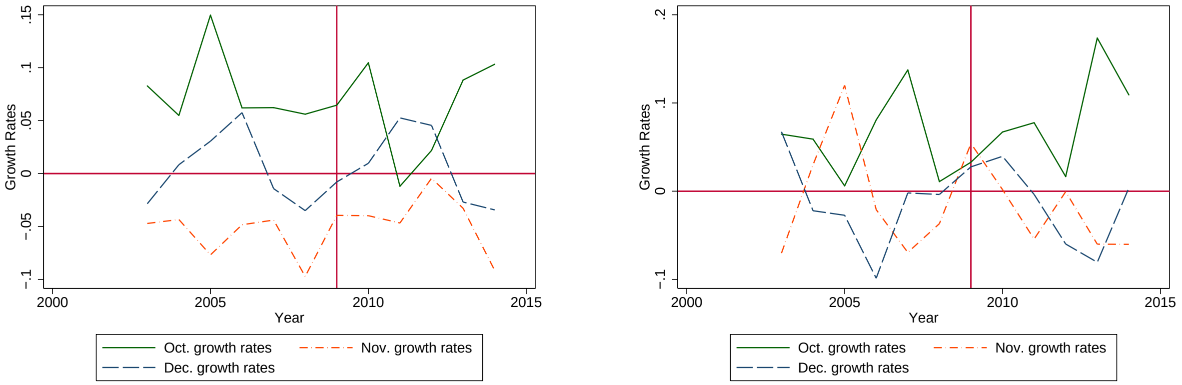
[30] Although there were several alternative emissions abatement technologies approved as of January 2010, all of these technologies placed a significant burden on liner carriers involved in EU trade as well (P&O Ferrymasters).

to avoid rising trade costs. To address this potential issue, Figures 3a and 3b display October, November, and December growth rates of U.S.-EU trade by year. The figures show, that for both U.S. 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.

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



(a) U.S. Exports

(b) U.S. Imports

FIGURE 3. Average End-of-the-Year Monthly Growth Rates of U.S.-EU Trade

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 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

---

[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 23 in Appendix C.

[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 U.S. port-foreign country pairs.

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 U.S. 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

---

[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 U.S. port-foreign country pairs that respond to a common shock at the U.S. state level, as well as potential trade correlations across foreign countries that experience a common shock at the U.S. port or state level. To address these concerns, I have re-estimated the model clustering standard errors at the U.S. state-foreign country level, U.S. port level, and U.S. state level. In general, the statistical significance of coefficient estimates is robust to these variations in clustering and results are presented in Table 24 of Appendix C.

[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 U.S.-EU trade. The estimation sample includes monthly observations of U.S. containerized exports and imports to and from OECD and APEC countries. Since the U.S. 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 U.S. is the common trade partner for all trade observations, the inclusion of time fixed effects controls for the time variation of U.S. 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 U.S. trade related time varying unobservables. The results are presented in Table 25 of Appendix C and illustrate that the variation in trade policy outcomes is largely consistent against various fixed effects specifications.

of foreign countries through U.S. ports of entry, the empirical 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 U.S. 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 U.S. free trade agreements with OECD and APEC countries and an interaction term capturing any variation in the response of U.S.-EU trade to the Great Trade Collapse (GTC) relative to all other U.S. trade. In addition to these dummy variables, the vector Z also includes regional real U.S. 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 U.S. regional level, r.

This gives rise to the following empirical specification;

$$x_{ijpt} = exp\left(\beta_0 + \beta_1 ln(L_{it}) + \beta_2 ln(L_{jt}) + \beta_3 \delta_{jt} + \gamma ln\left(Z^r_{ijt}\right) + a_i + a_j + a_t + a_p\right)\epsilon_{ijpt}, \quad (3.16)$$

where the dependent variable, x_{ijpt}, reflects the value of trade facilitated from country i to country j through U.S. 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 U.S. trade with an EU country relative to U.S. trade with non-member countries due to the implementation of the low sulfur fuel requirement.

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 U.S. 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 U.S. trade; an identification that would be lost at national or yearly aggregation levels. The *USA Trade Online* dataset 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 U.S. Over the sample period, these ports account for roughly 98.70% and 97.75% of total U.S. container imports and exports, respectively.

---

[35] The selection of U.S. 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 U.S. 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 U.S. 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 26 in Appendix C.

The extensive trade data are complemented by U.S. and international total employment observations. Monthly data on total non-farm employment by U.S. 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 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 U.S. state-level are used to control for economic mass variation instead. The application of state-level, rather than national, U.S. employment data controls for local income variations that may vary from national trends and could potentially influence the local port-of-entry trade flows.[37]

As indicated in the previous section, the additional control variables include U.S. free trade agreements and monthly observations on regional U.S. 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

---

[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*.

[37] As part of the robustness analysis, I test whether the empirical findings are sensitive to the exclusion of state-level U.S. employment. The results, presented in Panel 2 of Table 27 in Appendix C, demonstrate that the evidenced variation in policy-induced trade effects is robust against the exclusion of state-level U.S. 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 this dataset instead. According to the EIA, residual

U.S. 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 U.S. *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 9, I summarize the U.S. 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 U.S. containerized trade varies by the direction of trade (exports vs. imports), across countries, and treatment and control groups. While some countries, like China or Japan, hold considerable shares of total U.S. containerized imports, the majority of countries command shares of less than 1%. Similarly, the U.S. 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 U.S. container export market appears to be less concentrated, with market shares ranging from 0.03% to 13.02%, than the U.S. 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 U.S. trade partners (measured in average trade value) command over 50% market

---

fuel oils may contain No. 2 distillate in order to meet specifications (Wallace, nd) and thus, warrants its use as a proxy for HFO and low sulfur fuel prices.

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 U.S. 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 U.S. 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.

TABLE 9. U.S. Containerized Trade by Foreign Country

	(1)	(2)	(3)	(4)	(5)	(6)
		Imports			**Exports**	
Country	Trade ($ Mil.)	Trade Share (%)	BH Share (%)	Trade ($ Mil.)	Trade Share (%)	BH Share (%)
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

Continued on next page

---

[39] Since Japan and, in particular, China hold such market dominant positions concerning U.S. bilateral trade, I re-estimate the empirical model excluding both of these countries. The empirical results are given in Panel 4 of Table 26 in Appendix C and illustrate that estimated trade effects and their statistical significance are largely insensitive to the exclusion of these two countries.

Table 9 – *Continued*

	(1)	(2)	(3)	(4)	(5)	(6)
		Imports			**Exports**	
Country	Trade ($ Mil.)	Trade Share (%)	BH Share (%)	Trade ($ Mil.)	Trade Share (%)	BH Share (%)
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	-

Source: U.S. Census Bureau *USA Trade Online* database

Another interesting feature of the data concerns the share of backhaul transport markets for U.S. 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] The country-specific backhaul share data are presented in columns (3) and (6) of Table 9 and demonstrate that while the share of backhaul transport markets exhibits large heterogeneity across countries, it systematically varies across U.S. exports and imports.[41] In particular, as columns (3) and (6) illustrate, U.S. containerized exports tend to be facilitated in backhaul transport markets, while U.S. containerized imports typically represent a fronthaul transport market. That is, on a round trip facilitating bilateral trade between the U.S. and an OECD or APEC country, the majority of U.S. containerized imports from these countries reflect a fronthaul market for international carriers, while the majority of U.S. containerized exports to these countries reflect a backhaul market for these carriers.

In fact, given this sample, only 28.7% of the total U.S. 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 sample U.S. containerized exports to EU member countries and 70.7% of the sample U.S. exports to non-member countries are facilitated in backhaul transport markets. This shows that there is no inherent difference

---

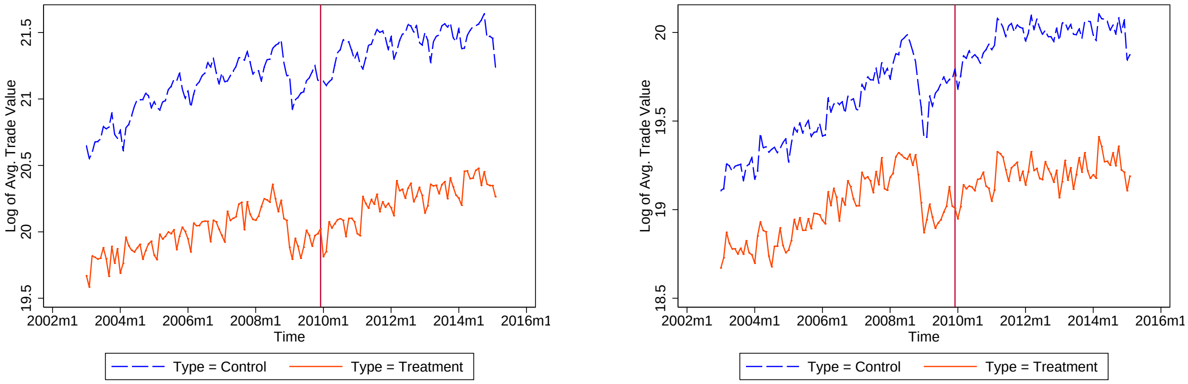
[40] Average shipment durations between the U.S. and Asia or Europe can range from 8 to approximately 30 days depending on the port of origin and destination. To address the possible one month lag between the fronthaul and backhaul route on a given round trip between the U.S. and an Asian or European country, I perform several robustness checks where the backhaul transport market is defined by comparing this month's U.S. imports(exports) to last month's U.S. exports(imports) for the same U.S. 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 28 of Appendix C.

[41] While the primary estimates rely on the backhaul identification at the U.S. port-foreign country level, actual shipping routes may include several stops at a few major U.S. ports and foreign countries. The existence of these primary transatlantic and transpacific shipping routes may alter the fronthaul and backhaul definitions assigned to each U.S. port-foreign country observation. In an attempt to match these shipment patterns and address potential concerns, I aggregate the bilateral U.S. 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 29 in Appendix C.

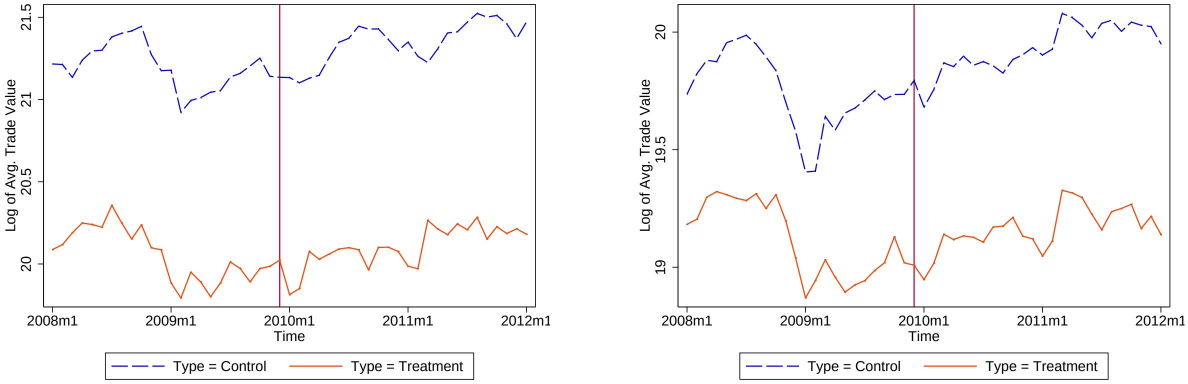
between the backhaul shares of treatment and control groups, but systematic variation across U.S. containerized imports and exports. Since bilateral U.S. trade tends to be imbalanced, the theoretical findings suggests that maritime transport policy applied to both U.S. containerized imports and exports should, in fact, produce very different responses in U.S. 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 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 4a and 4b illustrate the time path of logged U.S. containerized trade facilitated in fronthaul and backhaul transport markets comparing the trends involving U.S. trade with EU member and non-member countries over the entire sample period. Both figures present supporting evidence of the initial observations from Table 9. That is, U.S. 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 4a and 4b 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 4a and 4b provide no immediate insight concerning the potential treatment effects. To alleviate this issue, Figures 4c and 4d 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 4c and 4d, it appears that fronthaul and backhaul U.S. trade with either the treatment or control group



(a) Fronthaul (b) Backhaul



(c) Fronthaul (d) Backhaul

FIGURE 4. U.S. Trade Flows across Treatment & Control Groups by Transport Market

declines around the treatment date. However, Figures 4c and 4d 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 U.S. trade from seasonal and otherwise noisy variation and provide clear quantitative insights into the potential heterogeneity of trade policy outcomes across fronthaul and backhaul transport markets.

Results

In this section, I first present the empirical findings obtained from the gravity equation estimations of bilateral U.S. containerized trade with OECD and APEC countries. An extension of the analysis further differentiates trade effects across the balanced and imbalanced bilateral trade 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 U.S. 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 trade imbalance data and deducing the suggested implications across developing versus developed countries and geographic regions. Overall, these data suggest that transport-related trade effects are expected to be consistently larger for low rather than high income countries, but to vary dynamically across geographic regions.

Primary Results

The empirical results for the gravity equation estimation using the PPML estimator are presented in Table 10. The estimations differentiate potentially varying policy effects between the full sample including U.S. containerized exports and imports, as well as each of these trade categories separately. The full sample estimation results, given in column (1) of Table 10, reveal a negative, yet statistically insignificant, effect of the low sulfur fuel requirement on bilateral U.S.-EU trade, relative to all other bilateral U.S. containerized trade with OECD and APEC countries. This finding, however, is without distinction between U.S. exports and imports. Differentiation between the two, presented in columns (2) and (3) of Table 10, unmasks a small and statistically insignificant effect on U.S. containerized imports, but large and statistically significant export treatment effect. That is, U.S. containerized imports from EU countries experience no statistically significant reduction in response to the implementation of EU Directive 2005/32/EC, while U.S. 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 U.S. exports as well as loading U.S. imports, one would expect both U.S.-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 U.S. exports and imports are generally imbalanced and U.S. exports are mainly facilitated in backhaul transport markets, this finding suggests that U.S. exports should experience a larger decline in response to the low sulfur fuel requirement compared to U.S. 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 U.S. imports and exports. The results are given in columns (4) and (5) of Table 10 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 U.S.-EU trade experiences a statistically significant 9.87% reduction in response to the EU environmental policy relative to all other U.S. containerized backhaul trade with other OECD and APEC countries.

TABLE 10. ATE - PPML

VARIABLES	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
ATE, (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

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 that may arise, pertains to the difference in magnitudes of the statistically significant treatment effects on U.S. exports to EU countries compared to U.S.-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 U.S. exports. However, as the summary statistics in Table 9 reveal, not all U.S. containerized exports are transported in backhaul markets. Since fronthaul markets show no statistically significant effect, the overall reduction of U.S. 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 11 present the average fronthaul and backhaul treatment effects restricting the sample to observations where the value of backhaul U.S. trade is at least half of the value of fronthaul U.S. trade ($\eta = min(x_{ijpt}/x_{jipt})/max(x_{ijpt}, x_{jipt}) > 0.5$). In contrast, Columns (3) and (4) of Table 11 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.

TABLE 11. ATE - 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	-0.059	-0.080	-0.026	-0.036
ATE, (δ)	(0.085)	(0.091)	(0.116)	(0.119)
Panel 2	-0.068	-0.091	-0.061	-0.072
ATE, (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

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 11, suggest nearly identical fronthaul and

---

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

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 11, 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 in 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 U.S. trade imbalances. Figure 5 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.

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 empirical results that support the initial findings at the aggregate level. That is, the low sulfur fuel requirement is a larger deterrent to U.S.-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 U.S. 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

---

[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.

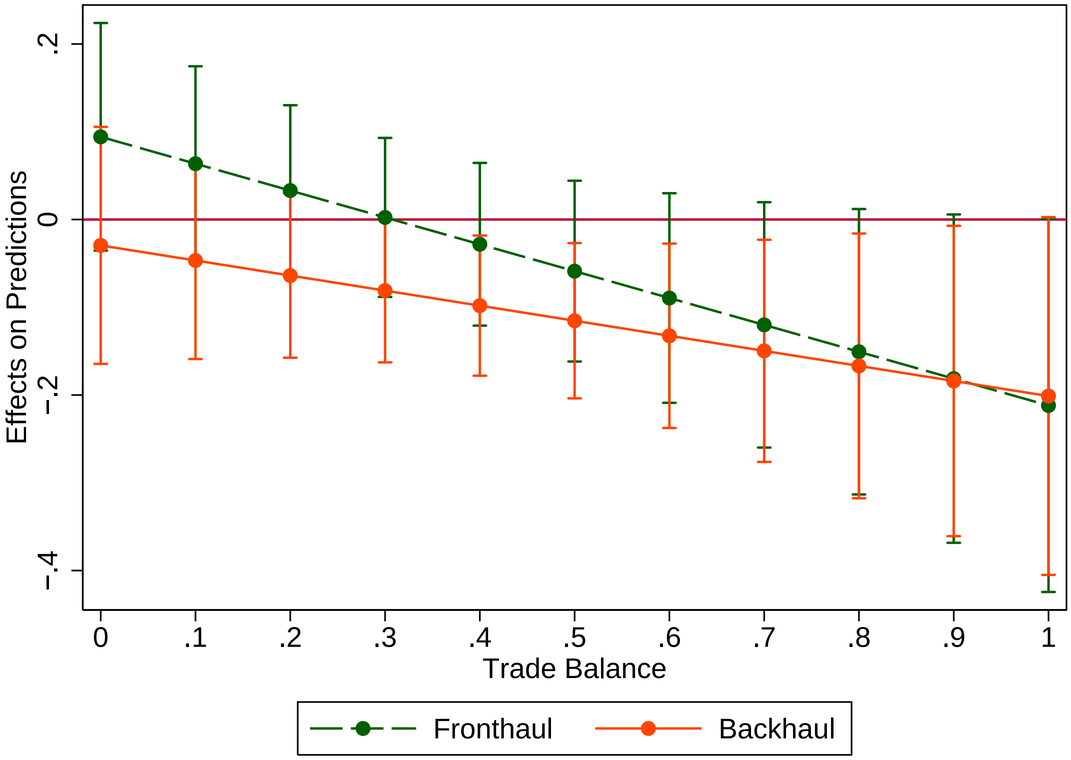


FIGURE 5. Marginal Treatment Effects by Transport Market and Trade Imbalance

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] The categorization of products also follows Korinek (2011) and is therefore, limited to

---

[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.

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 12 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 U.S. imports from EU members, are small and statistically insignificant. In contrast, with the exception of U.S. exports to EU members, the EU Directive has large, negative, and statistically significantly different treatment effects on all U.S.-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 U.S.-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 U.S. exports and imports to and from EU members and has led to a decline in U.S.-EU trade facilitated in both fronthaul and backhaul transport markets. A comparison of the fronthaul and backhaul high *ad valorem* transport cost product treatment effects, given in columns (4) and (5) of Table 12, illustrates that U.S.-

---

[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 12. ATE - Disaggregated Product Group Level

VARIABLES	(1) Full Sample	(2) Imports	(3) Exports	(4) Fronthaul	(5) Backhaul
ATE, (δ) (low *ad valorem* transport costs)	0.047	0.098*	-0.061	0.049	-0.013
	(0.045)	(0.052)	(0.052)	(0.052)	(0.059)
Differential ATE (high *ad valorem* transport costs)	-0.122***	-0.136**	-0.073	-0.129**	-0.185***
	(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

EU trade of these products experienced a larger decline in backhaul transport markets. In fact, the point estimates of column (5) show that backhaul U.S.-EU trade declined by 17.93% in response to the EU Directive relative to the previously indicated 7.72% decline of fronthaul U.S.-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 12.

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 23-29 of Appendix C.[48]

DID Specifications

At a fundamental level, the first robustness check tests the appropriateness of the DID estimator. Panels 2 and 3 of Table 23 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 U.S. port-foreign country level, this robustness analysis involves clustered standard errors at the U.S. state-foreign country, U.S. port and U.S. state levels. These changes in the level of cluster aggregation explore potential cluster correlations across ports and foreign trade partners. The respective

---

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

results are reported in columns 3 through 8 of Table 24 and illustrate that the statistical significance of the primary results is generally robust to these estimation adjustments.

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 U.S. region, state and port level. The respective results are reported in columns 3 through 8 of Table 25 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 26, 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 U.S. 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 27 report the empirical findings obtained from estimations excluding U.S. state level employment as well as U.S. 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 27, 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 27 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 U.S. exports and U.S. trade facilitated in backhaul transport markets.

Backhaul Identification

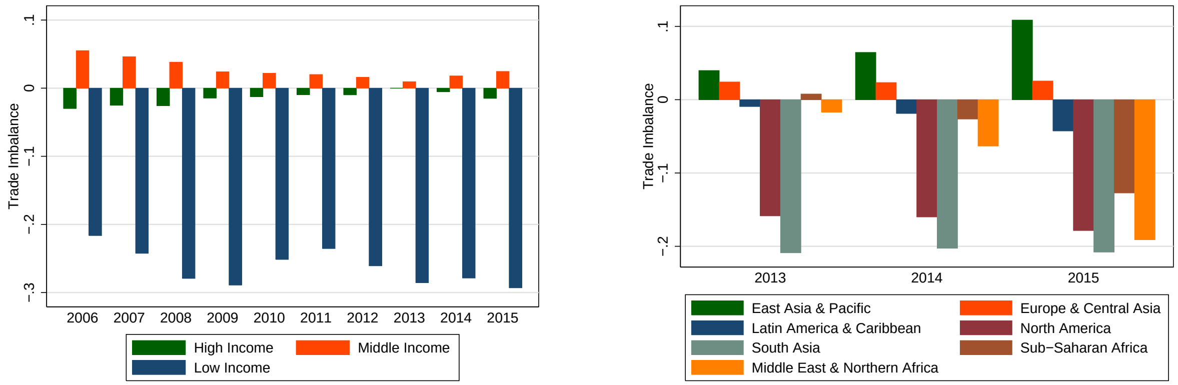
Lastly, I explore whether the empirical results are consistent across various changes to the identification of fronthaul and backhaul transport markets. These changes are intended to capture alternative transportation patterns of bilateral U.S. trade and are performed along the time and cross-sectional dimensions of the data. Given the fact that transatlantic as well as transpacific shipping between the U.S. 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 U.S. imports(exports) with last month's U.S. exports(imports) for the same U.S. port-foreign country pair. Estimations based on these redefined fronthaul and backhaul transport patterns yields robust results both in terms of the magnitude and statistical significanceF and are reported in Table 28.

In addition to these variations in shipment durations, it is possible that actual transatlantic and transpacific shipping routes are more complex than the simple U.S. port-foreign country trade observations available in the data used for this study. General shipping patterns, in fact, suggest that most of the bilateral U.S. trade considered in this study is handled by only a few major ports located in the U.S. 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, U.S. state-supranational and U.S. region-supranational levels and re-estimate the model. In general, the results presented in Panels 2 through 4 of Table 29 reflect point estimates of similar magnitude relative to the primary results given in Panel 1. While the statistical significance of these estimates varies for U.S. 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 U.S. 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.

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 U.S. 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 U.S. containerized exports than imports, which are mainly facilitated in backhaul, rather than fronthaul transport markets.

The implications of this study, however, are not only domestic in scope. As the results presented in Tables 10 through 12 as well as Figure 5 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 6a and 6b, 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 6a 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



(a) Income Level

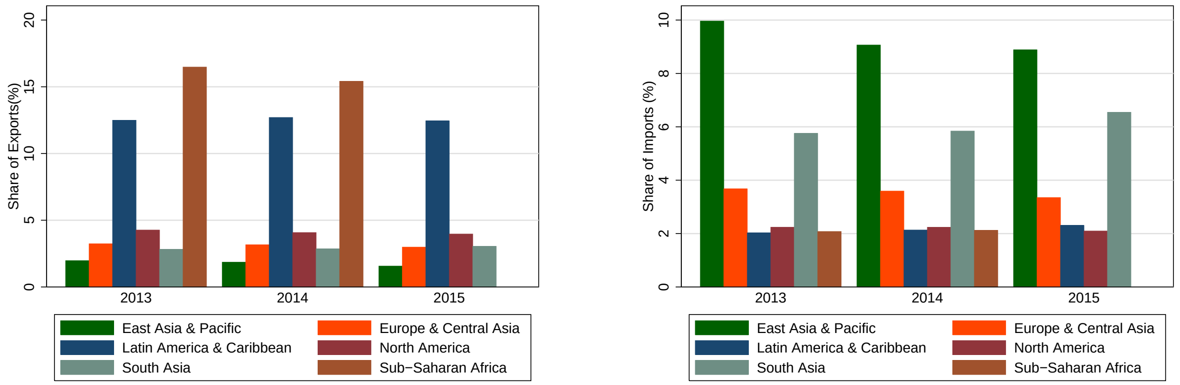
(b) Geogrpahic Region

FIGURE 6. Aggregate Trade Imbalance by Income Level and Geographic Region

much larger export and import volatility considering transport-related policy outcomes compared to middle to high income countries. Moreover, Figure 6a 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 6b 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 7a and 7b, the



(a) Export

(b) Import

FIGURE 7. Export and Import Share of Ore and Metal by Geographic Region

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.

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.

The empirical findings presented in 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 U.S.-EU exports and imports and caused a significant reduction in U.S.-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 U.S.-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.

The 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 U.S.-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 U.S.-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 U.S. policy intended to stimulate U.S. 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 U.S. trade as well. This feature of the analysis demonstrates that commercial policy intended to stimulate U.S. 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.

Bridge

Similar to the analysis conducted in this chapter, which has focused on the variation in trade effects across various transport markets, products and trade imbalances, the research provided in the following chapter considers trade disruptions and their variations across U.S. ports. In following chapter, however, I investigate the response of trade to a natural disaster, rather than a policy induced change in carrier costs. Again, the results point to systematic variation in trade effects. The dimension of this variation, however, is spatial in nature and dynamic over time.

CHAPTER IV

THE RESILIENCE OF INTERNATIONAL TRADE: AN EMPIRICAL EXAMINATION OF THE DYNAMIC SPATIAL TRADE EFFECTS OF NATURAL DISASTERS

Introduction

Natural disasters pose a constant threat to human life and economic activity, as evidenced by the recent earthquakes in Japan, Ecuador and Italy. According to the Centre for Research on the Epidemiology of Disasters (CRED), the global community has experienced an average of 384 natural disasters per year, over the last decade. As a result, close to 200 million people have been victimized yearly and annual average damages are estimated around $162 billion and increasing over time (CRED, 2015).

A variety of case studies indicate that this devastation not only encompasses the tragic loss of human life, but also the impairment of entire regional economic structures (Vigdor, 2008; Grenzeback et al., 2008). Upon the strike of a largely unanticipated natural disaster, housing, employment, and infrastructure, among others, are found to be in complete disarray. As international trade has grown and gained economic significance, its global presence has exposed it to the destruction and tragedy originating from natural disasters. The displacement of workers, destruction of product and capital, and impairment of infrastructure paramount to the facilitation of international trade can lead to substantial delays and/or rerouting of traded products. As such, natural disasters represent infrequent and uncertain trade costs, but yet have the potential to be immensely taxing, particularly at the local level. While the majority of commercial policies and academic research on trade is geared towards more common trade barriers, such as tariffs and transportation costs, relatively little attention has been paid to the linkages between trade and natural disasters. The existing studies suggest that natural disasters cause relatively small and short lived disruptions of aggregate international trade and heterogeneous responses across countries, industries, firms and products (Gassebner et al., 2010; Oh and Reuveny, 2010; Ando and Kimura, 2012; Martincus and Blyde, 2013).

In this study, I build on this small strand of the economic literature and provide a novel analysis of the natural disaster induced trade effects at the regional and port level. To this end, I build on the traditional gravity model of trade and extend it to capture the dynamic and spatial variation of natural disaster induced trade effects and account for the spatial correlation of local trade flows. The resulting spatial econometric model is applied to U.S. port level trade data from August 2003 to August 2013. Identification of the spatial heterogeneity in natural disaster induced trade effects is based on the exogenous variation in trade caused by Hurricane Katrina. Evaluations of the treatment effects at the aggregate or regional level produce statistically insignificant estimates that are consistent with the findings of the previous trade literature (Parsons, 2014).

In contrast to these aggregate estimates, I also investigate trade disruptions at the disaggregated local port level. The empirical results provide novel evidence of statistically significant trade disruptions. The port-specific treatment effects vary over time and strongly depend on the port's distance to Katrina's epicenter as well as various characteristics, such as harbor type and entry restrictions. While ports of New Orleans, Louisiana, and Gulfport, Mississippi, exhibit economically and statistically significant reductions in trade, the nearest ports of Mobile, Alabama, and Panama City, Florida, experience substantial and statistically significant increases in trade; a finding that is true both across the value of trade and the number of traded products. Regardless of whether the positive or negative trade disruptions are considered, I find that the impact of Hurricane Katrina exponentially vanishes as distance to its epicenter rises.

As expected, disruptions in exports are estimated to be more sensitive to distance than those of imports. Driving the resilience of international trade, this spatial distribution of counteracting trade effects leads to profound short-run disruptions at the local port level, but negligible effects in aggregate.

In addition to this static spatial analysis, I also consider the dynamic changes of these natural disaster induced trade effects over time. The case study of Hurricane Katrina provides important insights into the evolution of the spatially heterogeneous trade effects. Differentiating the monthly impacts across first to sixth order contiguous ports, I find that the duration of the experienced trade effects is largely port specific. While some ports recover fairly quickly, others are estimated to have experienced a permanent long-run change to their trade volumes and growth. Trade facilitated through the port of New Orleans, for example, recovers from the drastic short-run reductions within the first one to two years following treatment, while the port of Gulfport exhibits only a partial recovery that results in permanent reductions of both exports and imports relative to pre Hurricane Katrina levels. The adjacent ports reflect similar heterogeneous dynamics. While the port of Panama City experiences an immediate and persistent increase in trade, the port of Mobile shows a long-run increase in the growth rates of trade triggered by Hurricane Katrina.

The estimation of these spatially heterogeneous and dynamic trade effects delivers novel evidence in support of the *static* and *dynamic* resilience of international trade as defined by Rose (2007). In his study, the author describes *static* resilience as the ability of the economic system to maximize output based on the remaining, after-shock resources and *dynamic* resilience as the speed of recovery of the economy post natural disasters.[1]

---

[1] Rose and Wei (2013) develop an input-output type model to simulate the macroeconomic effects of a hypothetical port shutdown and illustrate several mechanisms of resiliency, most important of which is the ability to reroute international and domestic trade.

Based on these definitions and the empirical results obtained in this study, the static resilience of trade is founded in the ability of international carriers to use the remaining local infrastructure to provide alternative channels of trade facilitation - a finding that is of particular interest to policy makers in developing countries which continue to experience significant reductions in output growth due to natural disasters. The dynamic resilience of trade is shown to be driven by port-specific recovery as well as permanent port choice alterations.

Conducting these analyses, my research contributes to the existing literature in several ways. To the best of my knowledge, this study is the first to identify the spatial heterogeneity of natural disaster induced trade effects and consider their short-run and long-run spatial distribution. The empirical findings offer insights into the dynamic response of the international transport sector and domestic infrastructure network to local trade disruptions and point to the importance of these mechanisms in mitigating aggregate repercussions. As such, the estimated spatial and dynamic variation in trade effects presented in this study provide supporting evidence of the static and dynamic resilience of international trade and identify the specific channels that empower this pliancy.

The remaining parts of the paper are organized as follows: Section 2 presents an overview of the evolution of natural disasters and their devastating consequences, while also providing detailed background information on Hurricane Katrina and its specific effects. Section 3 offers a literature review focused on research pertaining to trade cost, its linkages to natural disasters and the resulting trade disruptions. To analyze the dynamic spatial variation in trade effects, a theoretical gravity model is developed in Section 4 and the resulting empirical specification is presented in section 5. The U.S. port level trade data employed in this study are summarized in Section 6, while the empirical results are discussed in section 7. Section 8 concludes this study and points to the significance of the empirical results as well as areas of further inquiry.

Institutional Background

As Blonigen and Wilson (2013) point out, international trade has been growing for decades and has exhibited a growth rate much larger than that of world Gross Domestic Product (GDP). The growing importance and global presence of international trade have led to its exposure to the destruction and challenges originating from a host of natural disasters in all corners of the world. According to CRED, natural disasters frequently occur across all continents and cause significant human losses and economic damages. In fact, CRED reports that over the last 20 years 6,457 weather-related disasters were recorded worldwide and that these natural disasters have claimed over 600,000 lives in total (CRED, 2015). Table 13 is based on the data presented in CRED's annual disaster statistical report of 2014 and provides continental averages concerning the frequency, number of overall victims and economic damages caused by all types of natural disasters over the time period from 2004 through 2013.

These data demonstrate that natural disasters are, indeed, frequent and global events. More importantly, the statistics show that recent natural disasters have caused substantial human and economic losses with roughly 200 million people affected annually and economic damages reaching a staggering $162 billion per year, on average. However, the data presented in Table 13 also reveal that the human and economic impacts of natural disasters vary greatly across continents. While an annual average of 69 natural disasters affected over 27 million people in Africa, natural disasters of similar average frequency in America and Europe affected *only* 9.82 and 0.64 million people, respectively. In contrast, average annual economic damages due to these natural disasters range from

$67.97 billion in America and $13.45 billion in Europe to $0.58 billion in Africa. Out of all continents, Asia is most affected with an annual average of over 160 million victims and over $75 billion in economic damages caused by an average 156 natural disasters per year (Guha-Sapir et al., 2015).

TABLE 13. Average Continental Disaster Impact

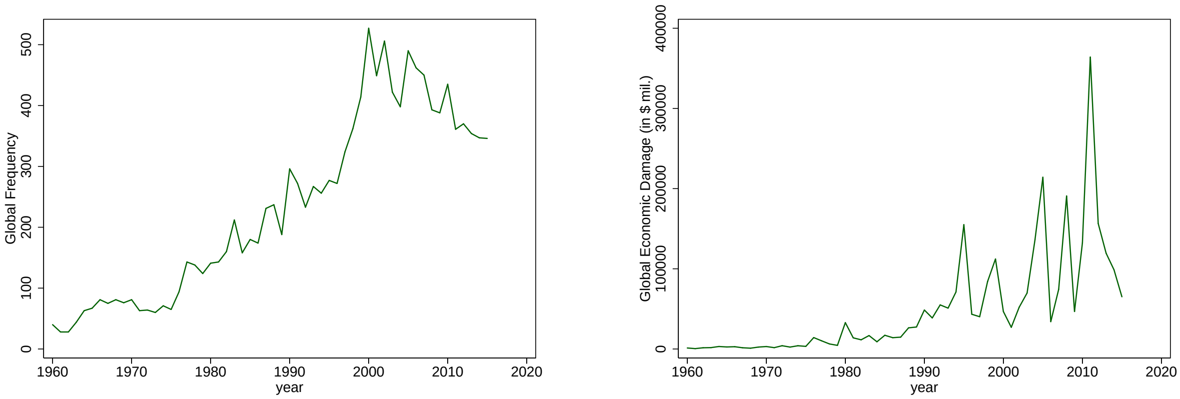
Continent	Frequency	Victims (mil.)	Damages (2014 $ bil.)
Africa	69	27.86	0.58
America	91	9.82	67.97
Asia	156	160.71	75.27
Europe	54	0.64	13.45
Oceania	14	0.19	5.26
Global	384	199.23	162.53

The data presented mark the 2004 through 2013 averages across all types of disasters.
Sources: *Centre for Research on the Epidemiology of Disasters*, Annual Disaster Statistical Review 2014

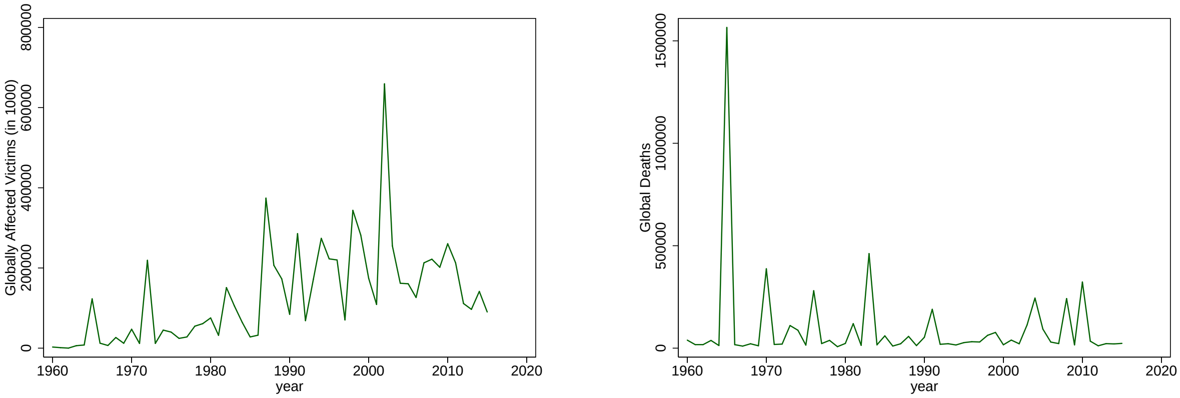
In addition to these average impacts of natural disasters, their historical trends in frequency and the evolution of the resulting human losses and economic damages are of considerable interest as well. When considering these dynamic developments of natural disasters, several key aspects, such as changes in exposure or destructive force, come into play. While Kunkel et al. (1999) report that recent demographic trends have led to an increasing population and property density in heavily disaster stricken regions, research by Emanuel (2005) points out that the power dissipation of tropical cyclones, for example, has doubled over the last century. Data collected by CRED and published in the International Disaster Database (EM-DAT), give insight into the efficacy of these observations. Figures 8a-8d display the annual global frequency of natural disasters and the resulting global economic damages, the overall number of victims affected and the number of deaths caused by these catastrophes.

Figure 8a shows that the period from 1960 to about 2000 saw a sharp ten-fold increase in natural disasters, whereas the more recent history suggests a downward trend concerning their frequency. Matching the historical increase in natural disaster frequency, Figures 8b and 8c illustrate that annual global economic damages and the number of people affected by these disasters are also increasing over the sample period from 1960 to 2000. However, these positive trends are more gradual and exhibit much larger volatility compared to the steep and rather smooth increase concerning the frequency of natural disasters. The recent reduction in disaster frequency is accompanied by a decline in the number of affected people, whereas economic damages do not reflect this downturn. This finding supports the arguments made by Kunkel et al. (1999) and Emanuel (2005) that even less frequent disasters can cause significant overall losses due to increases in economic vulnerability and a rise in the destructive force of the most recent natural disasters. Despite these dispiriting findings, the lethality of natural disasters, depicted in Figure 8d, encouragingly does not match the historic rise in their frequency, but appears to be rather disaster-specific instead.

The combination of larger populations subjecting themselves to the potential havoc of natural disasters, the growth of and increasing dependence on international trade and the rise in the destructive force of these natural disasters suggest potentially intensifying disruptions of international trade and supply chains. While some empirical studies consider the average effect of natural disaster on aggregate trade, this study identifies the dynamic and spatially heterogeneous trade effects via the variation caused by a single event, Hurricane Katrina. Hurricane Katrina is widely recognized for its immense devastation that caused tremendous hardship in human life and economic outcomes. According to Grenzeback et al. (2008), Katrina was the costliest and most destructive



(a) Frequency (b) Damages



(c) Reach (d) Lethality

FIGURE 8. Global Disaster Trends (1960-2015)

natural disaster ever experienced by the U.S.[2] causing over 1,800 deaths and an estimated $149 billion in direct and indirect economic losses (Hallegatte, 2008).

As depicted in Figure 9, Hurricane Katrina originated around the Bahamas and made its first landfall as a Category 1 hurricane in Florida on August 25th of 2005. After causing modest disruptions in Florida, the windstorm moved to the Gulf of Mexico, where it rapidly intensified and developed into a Category 5 hurricane at its peak. Its second landfall occurred in the state of Louisiana on August 29th, 2005, with sustained winds of

---

[2] While Grenzeback and Lukman's assessment is based on nominal values, Pielke Jr et al. (2008) show that in normalized terms Hurricane Katrina actually caused the second largest losses in U.S. history behind the Great Miami storm of 1926.

Source: US National Park Service

FIGURE 9. Geographical Movement and Strength of Hurricane Katrina

125 mph. Upon this second landfall, the havoc caused by Hurricane Katrina was felt along the majority of the U.S. Gulf coast severely affecting the coastal regions of Louisiana and Mississippi.

In addition to the tragic loss of human life, Hurricane Katrina's wreckage extended across the entire regional economic structure and even to the national level. Based on early estimations, Holtz-Eakin (2005) argued that the effects of Hurricane Katrina were expected to lower U.S. output growth by 0.5 percentage points in the short-run, whereas recovery efforts were expected to reverse this effect by 2006. The underlying causes for this initial decline in the growth of aggregate income range from extensive reductions in employment and housing due to the flooding of New Orleans[3], the destruction of physical capital[4], and trade disruptions caused by the severe impairment of the regional infrastructure. According to Grenzeback et al. (2008), the infrastructure of the U.S. coastal region of Louisiana, Mississippi and Alabama experienced substantial ruination encompassing damages to road, rail and port networks. Taking account of the specific damages, the authors point to the destruction of bridges, specific railways, the ports of New Orleans and Gulfport and Interstate 10, as well as the loss of electricity and closing of major waterways as the main factors determining this wreckage of the coastal infrastructure and potentially causing severe local trade disruptions.

Despite this detriment to the regional infrastructure, Parsons (2014) finds that aggregate U.S. imports were unaffected by the destructive force of Hurricane Katrina in the long-run. Upon providing supporting evidence of this aggregate finding, I evaluate the significance of trade disruptions at the regional and local levels. I find statistically significant local trade effects that are offsetting in aggregate and evidence the substantial resilience of international trade to natural disasters, even to those as monumental as Hurricane Katrina.

Literature Review

Within the international economics literature it has been widely recognized that trade costs are an integral determinant of international trade. In fact, regardless of

---

[3] Studies by Dolfman et al. (2007) and Vigdor (2008) show that Hurricane Katrina resulted in significant reductions of employers and employment (between 70,000 and 95,000 lost jobs) and the long-term displacement of over 150,000 people. Elliott and Pais (2006) as well as Masozera et al. (2007) find significant heterogeneity across the individually experienced losses and illustrate that this heterogeneity systematically varied by socioeconomic factors, such as race, class and income. In addition to these labor market effects, Vigdor (2008) reports that the New Orleans' availability of housing declined from 215,000 units in 2000 to 106,000 units in the aftermath of Hurricane Katrina.

[4] Holtz-Eakin (2005) estimate physical capital damages to total between $70 billion and $130 billion.

whether Krugman's 'New Trade Theory' (Krugman, 1980), the 'New-New Trade Theory' initially introduced by Melitz (2003), the gravity model (see, for example, Anderson and van Wincoop, 2003) or recent work on the classical model by Deardorff (2014) is considered, most theoretical derivations point to the significance of trade costs in the determination of the level and composition of international trade. In this section, I present a literature review concerning the micro- and macroeconomic effects of natural disasters, linkages to trade costs and resulting trade disruptions.

Trade costs manifest themselves in variety of ways and many of their facets have been analyzed in the trade literature. Brander and Spencer (1984), for example, study the effects of tariffs on international trade, whereas Clausing (2001) and Frankel and Rose (2002) focus on the impact of preferential trade agreements and monetary unions, respectively. Other studies have considered the trade effects of national borders (McCallum, 1995; Anderson and van Wincoop, 2003), cultural and linguistic differences (Egger and Lassmann, 2012) or transportation costs (Hummels and Skiba, 2004; Hummels, 2007; Friedt and Wilson, 2015; Friedt, 2016), for example.

While these types of barriers are relatively constant factors in the determination of international trade, trade disruptions caused by natural or man-made disasters represent rather irregular elements of overall trade costs. Nevertheless, these events can have significant long-term impacts on trade. Glick and Taylor (2010), Li and Sacko (2002), or Anderton and Carter (2001), for example, study the impacts of war and militarized conflict on international trade and find that the effects are generally long-lasting, lower the level and growth of international trade, impose large externalities on impartial countries, and vary by the level of uncertainty, duration and hostility. Alternative causes of man-made trade disruptions include acts of terrorism (see, for example, Egger and Gassebner, 2015) as well as economic sanctions (Caruso, 2005). In general, the empirical evidence concerning the trade effects of these alternative disasters varies by the severity of the event and the time horizon under consideration. Despite the fact that there is a large volume of studies providing theoretical and empirical analyses of the effects of trade costs on international trade, the consequences of natural disasters on trade have received very little attention.

Within the literature on natural disasters, many non-trade, microeconomic and macroeconomic aspects have been considered. On the microeconomic side, these issues include, for example, the natural disaster induced effects on labor markets (Belasen and Polachek, 2008), housing prices (Hallstrom and Smith, 2005), consumption volatility (Auffret, 2003) or supply chains (Altay and Ramirez, 2010). The general findings of this strand of the literature provide evidence of large economic distortions that exhibit significant heterogeneity across economic agents and over time. This variation in economic impacts is a reoccurring theme throughout the natural disaster's literature (see, for example, a survery by Cavallo and Noy, 2009) and applies to macroeconomic and trade related studies as well.

On the macroeconomic side, several studies have focused on primary issues, such as the effect of natural disasters on inflation (Noy, 2009), financial flows (Rasmussen, 2004; Yang, 2008) or output growth. While Yang (2008) finds a statistically significant increase in international financial flows for developing countries in response to natural disasters, evidence concerning their impact on output growth is rather mixed. Skidmore and Toya (2002), for example, find that a rise in the frequency of natural disasters causes an increase in the growth of aggregate income due to the substitution of investment towards human capital. Contrary to this finding, Strobl (2011) provides evidence of a very localized increase in output growth that is canceled out at the state level and leads to a negligible effect of natural disasters on the growth of aggregate output. In response to this variation concerning the effects on output growth, the literature has turned towards a more disaggregated analysis differentiating between developing and developed countries (see, for example, Strömberg, 2007; Crespo Cuaresma et al., 2008; Noy, 2009; Noy and Vu, 2010; Strobl, 2012) and identifying a variety of key factors determining the macroeconomic impact of natural disasters. Kahn (2005), Toya and Skidmore (2007), Raschky (2008) and Noy (2009), for example, show that countries with higher levels of democracy, government stability and education, greater openness, a more complete financial system, better investment climate and less inequality, in addition to higher income, experience fewer losses from natural disasters, on average.[5]

Of course, a potential explanation for this variation in disaster-induced aggregate economic outcomes may be the underlying heterogeneity of impacts at the regional level. While research by Burrus Jr et al. (2002) illustrates that output, employment and indirect business taxes in directly affected regions decline in response to hurricanes, Xiao and Nilawar (2013) demonstrate that income and employment in directly neighboring regions experience a short-run increase. Rose et al. (1997) and Lin et al. (2012) add that the effects of natural disasters vary not only geographically, but also across local industries.

Although international trade and its disruptions due to natural disasters can act as a significant catalyst for the discussed regional and aggregate variation in economic outcomes, research in this area is very limited. In a seminal study, Gassebner et al. (2010) analyze the effects of natural disasters on aggregate international trade. In general, the authors find that governance and economic size matter to the degree of devastation

---

[5] The definition of losses varies across these studies. Kahn (2005), Toya and Skidmore (2007) and Raschky (2008) measure the effects on deaths and damages due to natural disasters, whereas Noy (2009) captures losses by estimating the effects on output growth via an interaction term with the disaster variable. Although these studies yield very similar results overall, their conclusions pertaining to the effects of governments vary. Specifically, Noy (2009) finds that larger governments dampen the reduction in output growth, whereas Toya and Skidmore (2007) provide evidence indicating that larger governments increase the lethality of disasters.

on the import side, while exports experience a negative shock regardless of country characteristics. Research by Oh and Reuveny (2010) complements these findings showing that political risk is another important factor in the determination of trade effects caused by natural disasters. In contrast to these general analyses, studies by Andrade da Silva and Cernat (2012) and Meng et al. (2015) distinguish between the trade effects of natural disasters on developing versus developed countries. In general, the authors show that the estimated trade effects vary by economic and geographical size of the affected country as well as across imports and exports. Further disaggregation of these trade effects has provided evidence that the resulting trade disruptions, in fact, vary across the time horizons under consideration (Ando and Kimura, 2012; Parsons, 2014), the type of trade flow (Chang, 2000), industries and firms (Ando and Kimura, 2012; Martincus and Blyde, 2013) as well as product groups (Martincus and Blyde, 2013) and can lead to a change in trade composition (Ando and Kimura, 2012; Pelli and Tschopp, 2013).

Although this relatively small strand of the economic literature on natural disasters has provided substantial insights into the variation of natural disaster induced impacts on trade, little is known about the spatial heterogeneity of these trade effects.[6] The spatial econometric analysis presented in this study provides supporting evidence of the *static* and *dynamic* resilience of international trade by estimating the short-run and long-run spatial distribution of trade disruptions caused by Hurricane Katrina. The results offer an intuitive explanation for the generally small or even positive aggregate effects of natural disasters on trade and output. In addition, the empirical results point to the significance of infrastructure networks to dampen the economic devastation caused by natural disasters. Since, developing countries continue to experience reductions in

---

[6] The study by Martincus and Blyde (2013) exploits geo-referenced data on Chile to estimate the short-run impact of local infrastructure disruptions on trade and is perhaps most closely related to the present study.

output growth due to natural disasters, the specific resiliency channels identified in this research are of particular interest to international policy makers and one of the important remaining gaps in the literature as established by Cavallo and Noy (2009). Based on these findings, my research contributes to both the trade and natural disaster literature in several ways. First, to the best of my knowledge, this study is the first to identify the spatial heterogeneity of natural disaster induced trade effects. Second, the empirical findings offer insights into the dynamic responses of the international transport sector and domestic infrastructure network to these local disruptions. Third, the results concerning the spatial and dynamic variation in trade effects presented in this study provide supporting evidence of the static and dynamic resilience of international trade and identify the specific channels that empower this resiliency.

Theoretical Model

As the CRED data indicate, natural disasters inflict substantial damages to human life and economic activity. However, the empirical findings in the literature suggest that, while these devastations appear to be locally intensive in the short-run, they are rather negligible at the national level and insignificant in the long-run (Parsons, 2014). To test the validity of these findings with regards to international trade, I extend the standard model of trade to allow for time-varying natural disaster induced trade effects at the local port level. In particular, I follow the majority of the empirical trade literature and build on the conventional gravity equation extending it to include a spatially varying trade cost function that allows for the potential static and dynamic resilience of international trade to be estimated.

To begin, I base these extensions on the multi-country general equilibrium model derived by Anderson and van Wincoop (2003). To develop their model, the authors assume that the global economy consists of J trading countries. Each country, j, specializes in the production of a unique good which implies that goods are differentiated by origin. The supply of each of these goods is fixed and consumers in each country maximize utility based on their identical, homothetic, variety-loving CES preferences. Grounded on these assumptions, the theoretical derivation by Anderson and van Wincoop (2003) culminates in a structural gravity equation that expresses the value of country j's imports sourced from country i at time t, x_{ijt}, as a function of each countries aggregate income, Y_{it} and Y_{jt}, relative to world income, Y_{wt}, *ad valorem* trade costs, τ_{ijt} and multilateral resistance terms, P_{jt} and Π_{it}. Specifically, Anderson and van Wincoop (2003) present a static version of the following gravity equation:

$$x_{ijt} = \frac{Y_{it}Y_{jt}}{Y_{wt}} \frac{(t_{ijt})^{1-\sigma}}{P_{jt}^{1-\sigma}\Pi_{it}^{1-\sigma}}, \tag{4.1}$$

where the multilateral resistance terms are given by

$$P_j^{1-\sigma} = \sum_i \frac{Y_i}{Y^w} \left(\frac{t_{ij}}{\Pi_i}\right)^{1-\sigma} \tag{4.2a}$$

$$\Pi_i^{1-\sigma} = \sum_j \frac{Y_j}{Y^w} \left(\frac{t_{ij}}{P_j}\right)^{1-\sigma}. \tag{4.2b}$$

Following Egger and Gassebner (2015), I assume that *ad valorem* trade costs, $\tau_{ijt}^{1-\sigma}$, can be described by a multiplicative function of K individual elements, indexed by k, and represented as $\tau_{ijt}^{1-\sigma} = \Pi_{k=1}^{K}\tau_{kijt}^{1-\sigma}$. Further drawing on the notation introduced by Egger and Gassebner (2015), the kth element of the multiplicative trade costs function is captured by the kth observable trade-cost variable h_{kijt}, such that $\tau_{kijt}^{1-\sigma} = h_{kijt}^{\beta_{kt}}$. To reflect the spatial variation in trade costs due to natural disasters, I expand the dimension of the trade cost function and introduce the spatial notation, p, to indicate the dependence of trade costs on the location of the specific port of entry or exit, $\tau_{kpijt}^{1-\sigma} = h_{kpijt}^{\beta_{kpt}}$. Intuitively, one of these trade costs elements, for example, captures the natural disaster induced trade costs that are allowed to vary across ports at various distances from the given epicenter.

Specific to the present study, the kth trade-cost variable indicates the timing of Hurricane Katrina for each of the given ports at various distances to its epicenter. The β coefficient on this variable is intended to capture the resulting port-specific trade effects. Comparisons of these coefficients across ports and time give insights into the dynamic spatial heterogeneity of the disaster induced trade effects and provide a test for the hypothesized resilience of international trade. Log-linearizing the resulting gravity equation leads to the final theoretical expression of international trade flowing from country i to country j through port p at time t.

$$ln(x_{ijpt}) = ln(Y_{it}) + ln(Y_{jt}) - ln(Y_{wt}) + \sum_{k=1}^{K} \beta_{kpt} ln(h_{kijpt}) - ln(P_{jpt}^{1-\sigma}) - ln(\Pi_{ipt}^{1-\sigma}). \tag{4.3}$$

Empirical Model

Based on equation (4.3), I derive the stochastic specification of the previously described gravity model accounting for the dynamic and spatially varying trade costs. Moreover, I expand the econometric model to control for potential presence of spatial autocorrelation across U.S. ports. For the purposes of this study and simplifying the theoretical expression, I aggregate U.S. port-level trade across foreign countries. The resulting dependent variable, the log of U.S. aggregate trade through port p at time t (monthly frequency), $\ln(x_{pt})$, is modeled as a function of port-varying natural disaster induced trade costs and various fixed effects that control for the aforementioned multilateral resistance terms. More specifically, the set of fixed effects include port, a_p, and time, a_t, specific indicators that capture time-invariant port characteristics and national trends in macroeconomic and trade cost variables, such as national income or changes in free trade agreements and tariffs. The main trade cost component of interest includes a set of interacted dummy variables, $\tau_{p,t^* \pm s}$, each indicating a specific month before or after Hurricane Katrina for a given port of entry or exit. The specific timing of Hurricane Katrina's landfall in August of 2005 is indicated via t^*. Intuitively, $\tau_{p,t=t^*+1}$ indicates the disaster induced trade disruption at port, p, one month following Hurricane Katrina's landfall.

Since U.S. port-level trade flows and the unobservables influencing these transactions, u_{pt}, are potentially correlated across ports of entry and exit, I adopt the flexible spatial econometric model presented by LeSage and Pace (2009). This specification nests the spatial autoregression (SAR), spatial error (SEM) and spatial autocorrelation (SAC) models which allow for a spatially correlated dependent variable, $\rho W ln(x_{pt})$, and/or error term, $u_{pt} = \lambda W u_{pt} + \epsilon_{pt}$. Given this specification of the stochastic component, ϵ_{pt} is a normally and independently distributed random error, while $\rho W ln(x_{pt})$ and $\lambda W u_{pt}$ consist of the spatial correlation coefficients, ρ and λ, as well as spatial weight matrix W. Of course, there are various weight matrices available when considering the final spatial econometric specification (Ord, 1975; LeSage and Pace, 2009). Since the distances between ports are non-uniform, a natural choice for the spatial weights may be an inverse distance measure which proposes that the spatial correlation across ports declines exponentially with the distance between a pair of ports (Cliff, 1969; Griffith, 1996; Getis, 2009). An alternative may be a row normalized contiguity matrix indicating each port's neighboring facilities irrespective of their distance.[7]

---

[7] The empirical results presented in section 7 and Appendix C are consistent across all weight matrix specifications including inverse distance based on nautical distances as well as contiguity matrices of order one through four.

Combining this stochastic structure with the original gravity specification yields the following empirical model;

$$\ln(x_{pt}) = \beta_0 + \rho W ln(x_{pt}) + \sum_{r=1}^{R}\sum_{p=2}^{P} \beta_{pr}\tau_{p,t^*-r} + \sum_{r=1}^{S}\sum_{p=2}^{P} \beta_{ps}\tau_{p,t^*+s} + a_p + a_t + u_{pt} \tag{4.4}$$

$$u_{pt} = \lambda W u_{pt} + \epsilon_{pt},$$

where 2 years of port-specific pre-treatment, $R = 24$, and 8 years of port-specific post treatment, $S = 96$, effects are considered. Given this specification, the SAR model is obtained when $\rho > 0$ and $\lambda = 0$, while the SEM model is nested via $\rho = 0$ and $\lambda > 0$. Alternatively, the SAC model assumes $\rho > 0$ and $\lambda > 0$. The parameters of interest capturing the dynamic and spatially distributed trade effects caused by Hurricane Katrina are given by β_{ps}. These parameters, along with pre-treatment indicators, β_{pr}, are evaluated in relation to the month of Hurricane Katrina's landfall, t^*, and a given port of reference, $p = 1$.

Data

The data used to estimate the empirical model specified by equation (4.4) have been obtained from various sources. The main variable of interest is given by U.S. containerized trade concerning both exports and imports at the container seaport of entry and exit level. These data are available through the *USA Trade Online* database by the *U.S. Census Bureau* and cover the entirety of U.S. bilateral trade facilitated through U.S. ports of entry and exit at monthly frequency. The time period considered in this study extends from August of 2003 to August of 2013. While *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 the largest forty ports of entry and exit have been included in the sample.[8] At the time of Hurricane Katrina's landfall, these forty ports account for roughly 98% and 96% of total U.S. containerized imports and exports, respectively.

The key variables of interest distinguishing the systematic variation in trade disruptions caused by Hurricane Katrina are based on longitudinal and latitudinal coordinates obtained from the World Port Index (WPI) compiled by the *National Geospatial-Intelligence Agency* and nautical port-to-port distances published by the *U.S. Department of Commerce* in collaboration with the *National Oceanic and Atmospheric Administration (NOAA)* and the *National Ocean Service*.[9] The distinction in local treatment effects is based on the spatial distribution of U.S. ports and their nautical distances from the epicenter of Hurricane Katrina's landfall, which has been approximately located around Waveland and Bay St. Louis, Mississippi. Based on the selection of ports under consideration and their geographic locations, the ports of New Orleans, LA, and Gulfport, MS, have been identified as those closest to the epicenter in the western and eastern direction, respectively, while the port of Mobile, AL is the only other sample port still within the hurricane warning zone. Other second or higher order contiguous ports are located in Florida and Texas or more remote U.S. states. The respective nautical epicenter distances of ports located in these and other states are presented in Tables 14 and 15.

To gain preliminary insights into the spatial and dynamic distribution of trade disruptions caused by Hurricane Katrina, a summary detailing the cross-sectional, spatial and time dimensions of the data is provided in Tables 14 and 15 as well as Figures 10 through 12f. In particular, Tables 14 and 15 provide the average port throughput of total exports and imports over a two year span pre and post Hurricane Katrina.

---

[8] Due to the need to control for spatial correlations and their unique locations, the ports of Honolulu, HI, and Ranier-Falls, MN, have been excluded from this sample.

[9] The port-to-port nautical distance matrix is presented in Table 30 in Appendix C

Column (1) of each table presents the nautical distances between a given port and the estimated epicenter of Hurricane Katrina, whereas columns (2) and (3) present the two year average trade flows pre and post its landfall. These data reveal that the majority of ports experienced an increase export and import throughput over this time period. The exceptions to this rule are the first order contiguous ports of New Orleans and Gulfport on the import side and Gulfport on the export side which exhibit substantial reductions in trade. Another irregularity that stands out from the general trend is given by the port of Panama City which experienced a twenty fold increase in imports and immense 198 fold increase in exports. Indicatively, as depicted by Figures 10 and 11, this port is a third order contiguous port just east of the hurricane warning zone, fortunately spared from its devastation and clearly benefiting from its proximity to the negatively disrupted ports.

TABLE 14. U.S. Port of Entry - Export Summary Pre & Post Hurricane Katrina

Ports	(1) Dist. to Epicenter	(2) Pre ($ mil.)	(3) Post ($ mil.)	(4) Share Pre (%)	(5) Share Post (%)	(6) Rank Pre	(7) Rank Post
Gulfport, MS	15.66	85.59	49.24	0.824	0.363	18	24
New Orleans, LA	40.44	222.06	251.18	2.137	1.850	14	15
Mobile, AL	113.67	9.41	17.09	0.091	0.126	28	29
Panama City, FL	237.67	0.16	31.79	0.002	0.234	41	27
Tampa, FL	428.67	4.53	7.65	0.044	0.056	31	31
Port Arthur, TX	481.44	1.25	3.41	0.012	0.025	40	35
Galveston, TX	486.44	6.53	6.79	0.063	0.050	30	32
Freeport, TX	529.44	15.38	18.61	0.148	0.137	27	28
Houston, TX	530.44	936.62	1,402.18	9.012	10.329	4	4
Corpus Christi, TX	595.44	1.61	1.91	0.015	0.014	36	40
Miami, FL	703.00	459.73	487.85	4.424	3.594	9	10
Port Everglades, FL	718.00	247.39	378.39	2.380	2.787	12	12
West Palm Beach, FL	759.00	60.84	87.74	0.585	0.646	21	20
Jacksonville, FL	1015.00	118.33	167.22	1.139	1.232	17	17
Brunswick, GA	1041.00	3.61	2.52	0.035	0.019	33	39
Savannah, GA	1096.00	549.61	834.52	5.288	6.147	8	7
Charleston, SC	1125.00	759.97	889.41	7.312	6.552	6	6
Wilmington, NC	1220.00	41.93	61.66	0.403	0.454	24	23

Continued on next page

Table 14 – *Continued*

Ports	(1) Dist. to Epicenter	(2) Pre ($ mil.)	(3) Post ($ mil.)	(4) Share Pre (%)	(5) Share Post (%)	(6) Rank Pre	(7) Rank Post
Newport News, VA	1458.00	764.62	1,025.70	7.357	7.556	5	5
Baltimore, MD	1584.00	210.27	276.79	2.023	2.039	15	13
Chester, PA	1624.00	58.17	105.29	0.560	0.776	22	19
Philadelphia, PA	1639.00	75.71	110.22	0.728	0.812	20	18
Perth Amboy, NJ	1642.00	1.32	3.96	0.013	0.029	39	34
Newark, NJ	1650.00	241.53	384.27	2.324	2.831	13	11
New York, NY	1662.00	1,135.75	1,596.33	10.928	11.759	2	2
Boston, MA	1900.00	50.27	73.22	0.484	0.539	23	21
Portland, ME	1940.00	3.60	2.86	0.035	0.021	34	38
Detroit, MI	3645.00	202.64	216.74	1.950	1.597	16	16
Port Huron, MI	3707.00	16.44	13.52	0.158	0.100	26	30
Chicago, IL	4278.00	25.68	34.13	0.247	0.251	25	25
San Diego, CA	4309.00	9.01	3.08	0.087	0.023	29	37
Long Beach, CA	4381.00	1,038.09	1,419.06	9.989	10.453	3	3
Los Angeles, CA	4382.00	1,280.06	1,644.61	12.317	12.115	1	1
Port Hueneme, CA	4456.00	2.12	3.31	0.020	0.024	35	36
San Francisco, CA	4712.00	4.06	5.37	0.039	0.040	32	33
Richmond, CA	4723.00	1.43	1.46	0.014	0.011	38	41
Oakland, CA	4767.00	575.55	668.37	5.538	4.923	7	8
Portland, OR	5330.00	84.62	65.60	0.814	0.483	19	22
Seattle, WA	5486.00	451.02	505.86	4.340	3.726	10	9
Tacoma, WA	5511.00	255.11	273.14	2.455	2.012	11	14

Source: U.S. Census Bureau *USA Trade Online* dataset

TABLE 15. U.S. Port of Entry - Import Summary Pre & Post Hurricane Katrina

Ports	(1) Dist. to Epicenter	(2) Pre ($ mil.)	(3) Post ($ mil.)	(4) Share Pre (%)	(5) Share Post (%)	(6) Rank Pre	(7) Rank Post
Gulfport, MS	15.66	190.94	116.85	0.550	0.271	17	22
New Orleans, LA	40.44	259.18	223.57	0.747	0.518	16	17
Mobile, AL	113.67	37.12	69.44	0.107	0.161	27	26
Panama City, FL	237.67	4.17	86.71	0.012	0.201	37	25
Tampa, FL	428.67	10.72	18.87	0.031	0.044	34	33
Port Arthur, TX	481.44	8.06	7.20	0.023	0.017	35	37
Galveston, TX	486.44	20.67	27.72	0.060	0.064	30	31
Freeport, TX	529.44	26.84	11.38	0.077	0.026	29	35
Houston, TX	530.44	999.29	1,433.85	2.881	3.322	10	10

Continued on next page

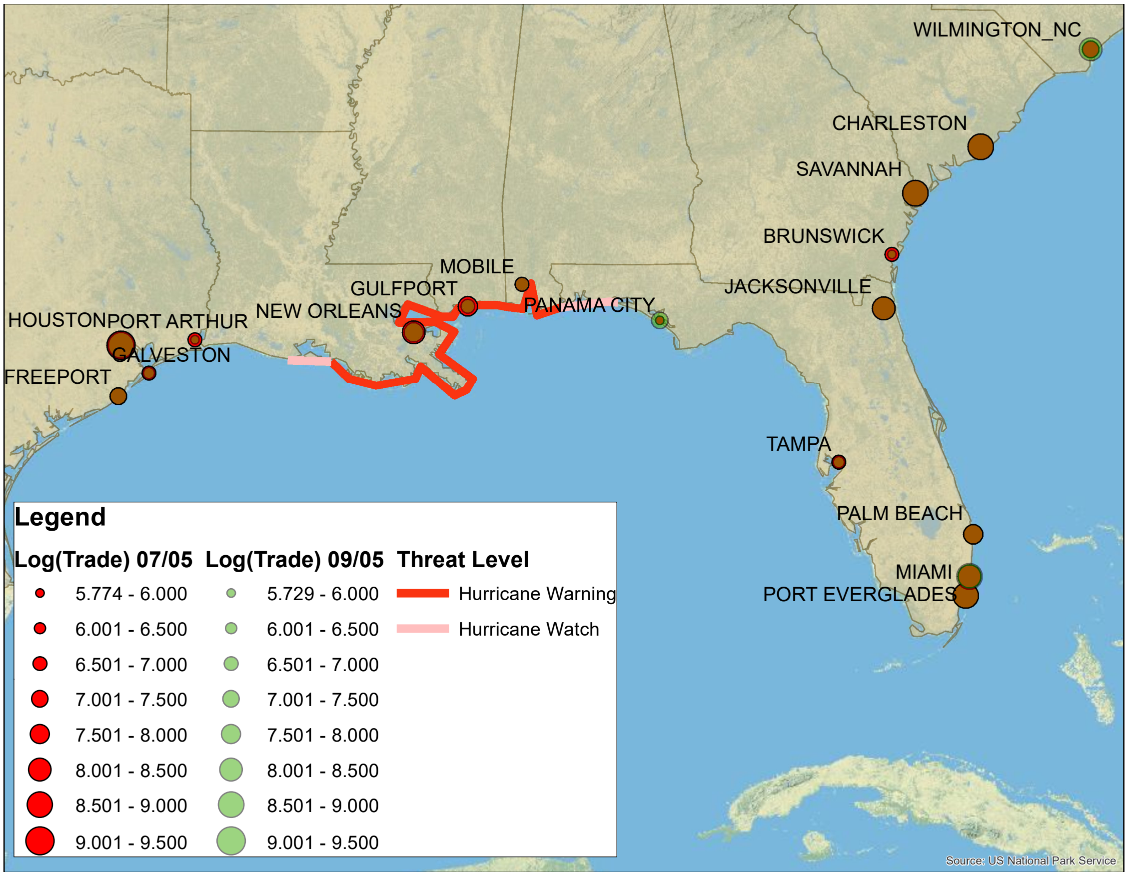
Table 15 – *Continued*

Ports	(1) Dist. to Epicenter	(2) Pre ($ mil.)	(3) Post ($ mil.)	(4) Share Pre (%)	(5) Share Post (%)	(6) Rank Pre	(7) Rank Post
Corpus Christi, TX	595.44	0.99	3.00	0.003	0.007	40	40
Miami, FL	703.00	821.43	850.75	2.368	1.971	11	12
Port Everglades, FL	718	428.57	531.95	1.236	1.232	14	14
West Palm Beach, FL	759.00	58.28	47.90	0.168	0.111	26	28
Jacksonville, FL	1015.00	85.63	119.77	0.247	0.277	22	21
Brunswick, GA	1041.00	131.40	88.36	0.379	0.205	21	24
Savannah, GA	1096.00	1,110.64	1,705.11	3.202	3.950	9	9
Charleston, SC	1125.00	2,001.17	2,463.87	5.769	5.708	4	4
Wilmington, NC	1220.00	71.40	113.37	0.206	0.263	25	23
Newport News, VA	1458.00	1,660.56	2,158.80	4.787	5.001	6	6
Baltimore, MD	1584.00	785.69	1,043.14	2.265	2.417	12	11
Chester, PA	1624.00	142.21	185.40	0.410	0.430	19	19
Philadelphia, PA	1639.00	266.94	389.88	0.770	0.903	15	15
Perth Amboy, NJ	1642.00	1.91	0.86	0.005	0.002	39	41
Newark, NJ	1650.00	4,474.18	5,512.94	12.899	12.772	2	2
New York, NY	1662.00	610.09	733.90	1.759	1.700	13	13
Boston, MA	1900.00	158.19	222.42	0.456	0.515	18	18
Portland, ME	1940.00	3.32	3.07	0.010	0.007	38	39
Detroit, MI	3645.00	13.59	19.43	0.039	0.045	33	32
Port Huron, MI	3707.00	5.34	6.01	0.015	0.014	36	38
Chicago, IL	4278.00	16.03	17.28	0.046	0.040	31	34
San Diego, CA	4309.00	74.63	165.40	0.215	0.383	23	20
Long Beach, CA	4381.00	3,491.18	4,236.57	10.065	9.815	3	3
Los Angeles, CA	4382.00	10,929.78	13,532.80	31.510	31.352	1	1
Port Hueneme, CA	4456.00	73.77	27.89	0.213	0.065	24	30
San Francisco, CA	4712.00	28.13	28.58	0.081	0.066	28	29
Richmond, CA	4723.00	14.89	8.86	0.043	0.021	32	36
Oakland, CA	4767.00	1,488.80	1,832.66	4.292	4.246	8	8
Portland, OR	5330.00	138.78	253.46	0.400	0.587	20	16
Seattle, WA	5486.00	1,917.51	2,231.22	5.528	5.169	5	5
Tacoma, WA	5511.00	1,537.71	1,899.13	4.433	4.400	7	7

Source: U.S. Census Bureau *USA Trade Online* dataset

Columns (4) and (5) of these tables present the shares of each port's throughput relative to average total trade prior to and in the aftermath of Hurricane Katrina. Based on these data, each port has been ranked before and after Katrina's landfall, with lower numbers representing larger market shares in U.S. trade. These rankings for exports and imports are given in columns (6) and (7) of Tables 14 and 15, respectively and point to spatial variation in trade disruptions. While the majority of ports experience minor changes in rank, ports closest to the epicenter demonstrate rather large relative adjustments. Gulfport, for example, exhibits a 6 and 5 point drop in export and import ranking, respectively, whereas the port of Panama City, for example, experiences a 14 and 12 point increase concerning these rankings. In contrast, the port of New Orleans, LA, displays rather small losses in export and import trade shares that results in a common one point drop in the respective rankings. While the former findings suggests that ports located closest to a disaster's epicenter tend to encounter significant negative or positive trade disruptions relative to other ports located at greater distances, the latter points to very idiosyncratic effects. Overall, the data presented in these tables provide supporting evidence of the local variation of trade disruptions across ports and point to the importance of modeling the disaggregated trade effects induced by natural disasters.

Building on this initial summary, Figures 10 and 11 provide insights into the short-run spatial distribution of the cross-sectional observations. In both figures, the geo-referenced ports are scaled by their one month pre and post Hurricane Katrina trade values. Overlaying the two trade values, a negative change in containerized trade is indicated by a larger red circle (i.e. Gulfport), while a positive change in trade is represented by a larger green circle (i.e. Panama City). Matching the previous medium-run observations, ports within or just outside of the hurricane warning zone experience the largest changes in trade after the landfall of Hurricane Katrina. Regardless of whether exports or imports are considered, the port of Panama City clearly indicates increases in trade post Hurricane Katrina, while the ports of Gulfport and New Orleans tend to exhibit the largest losses in trade. In contrast, the geo-referenced ports at greater distances appear to experience relatively small or no visible changes in trade.



Source: US National Park Service

FIGURE 10. Geo-referenced Port Exports Pre & Post Hurricane Katrina

To investigate the spatial variation and duration of local trade effects, the trends of U.S. trade at the national, regional and local level are considered next. Figures 12a and 12b illustrate that aggregate U.S. exports and imports exhibit positive overall growth, albeit large seasonal variations. The vertical red line indicates August, 2005, the month during which Hurricane Katrina occurred. Both figures demonstrate that compared to common seasonal variation, the aggregate trade effects of Hurricane Katrina appear negligible and without any long-term impact. To explore the apparent disconnect between these aggregate observations and significant trade disruptions indicated in Tables 14 and 15 as well as Figures 10 and 11, the analysis continues at the disaggregated regional trade level. Figures 12c and 12d present regional trade shares and reveal slight variations from

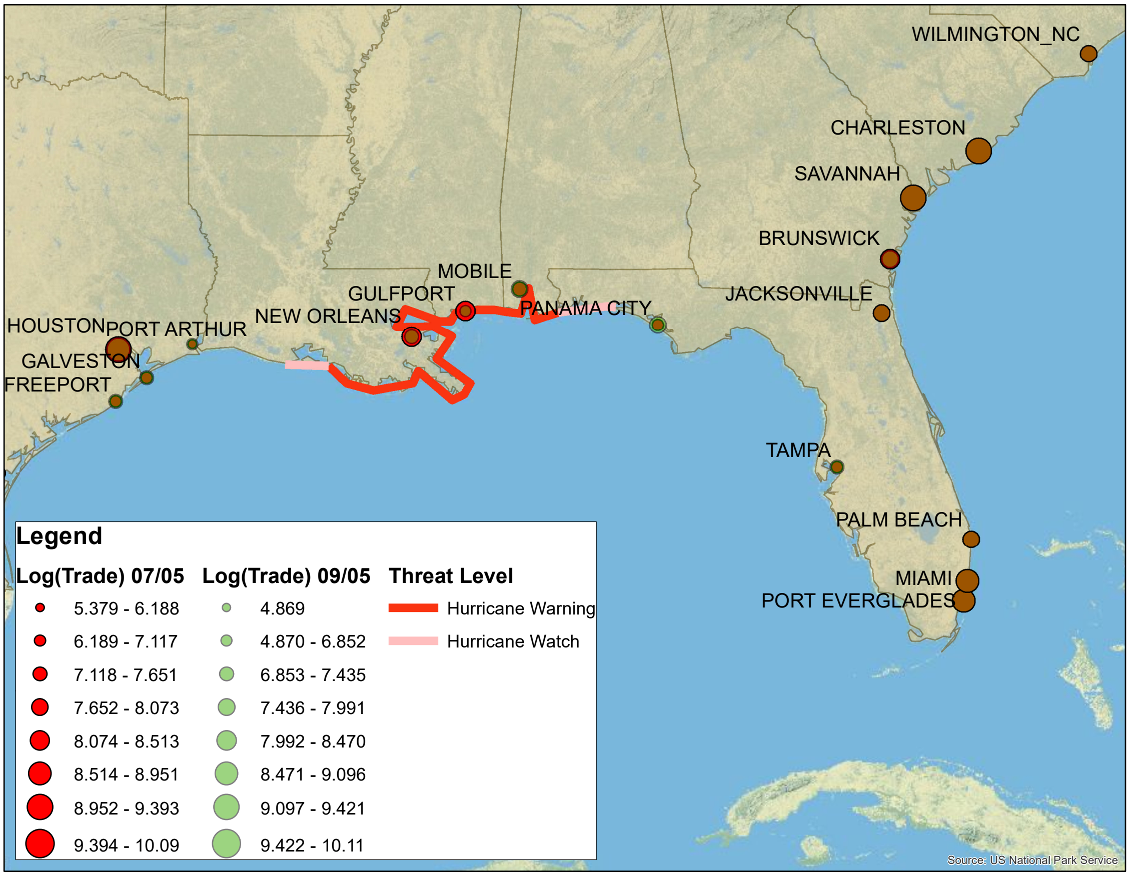


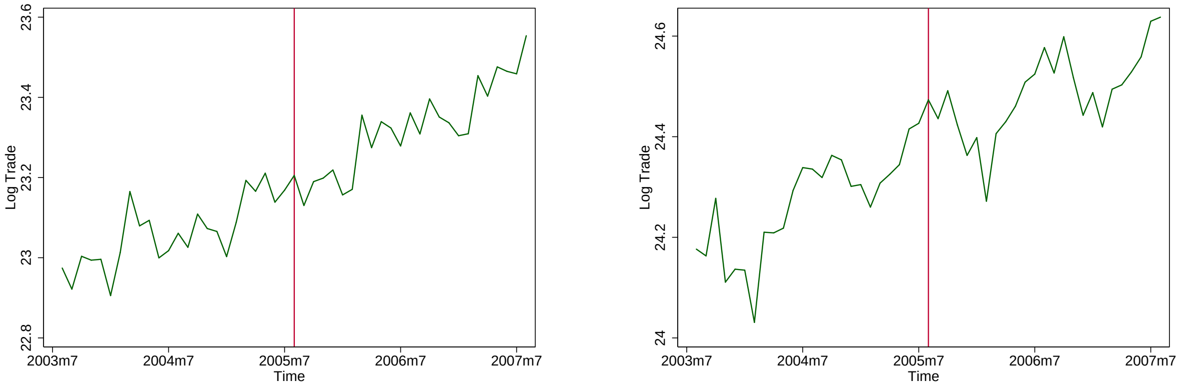
FIGURE 11. Geo-referenced Port Imports Pre & Post Hurricane Katrina

the aggregate conclusions. That is, Figure 12c shows that U.S. exports facilitated through ports located in the *U.S. Gulf Coast* (including Alabama, Louisiana, Mississippi and Texas) faced a sharp but temporary decline, while the adjacent *Lower Atlantic* region (including Florida, Georgia, North Carolina, South Carolina and Virginia) responded with an apparent increase in relative exports.[10] In addition to that, Figure 12c reveals that the share of exports held by the remaining U.S. regions remains rather stable during this period. In contrast, to this preliminary evidence of small short-run trade disruptions at the regional export level, Figure 12d presents a much less noticeable impact of Hurricane

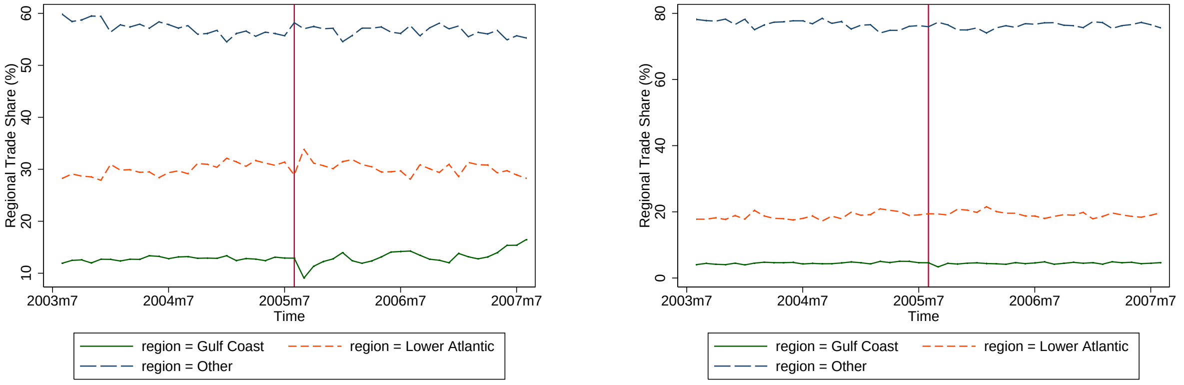
---

[10] These regional definitions follow the categorization by the *U.S. Energy Information Administration*.

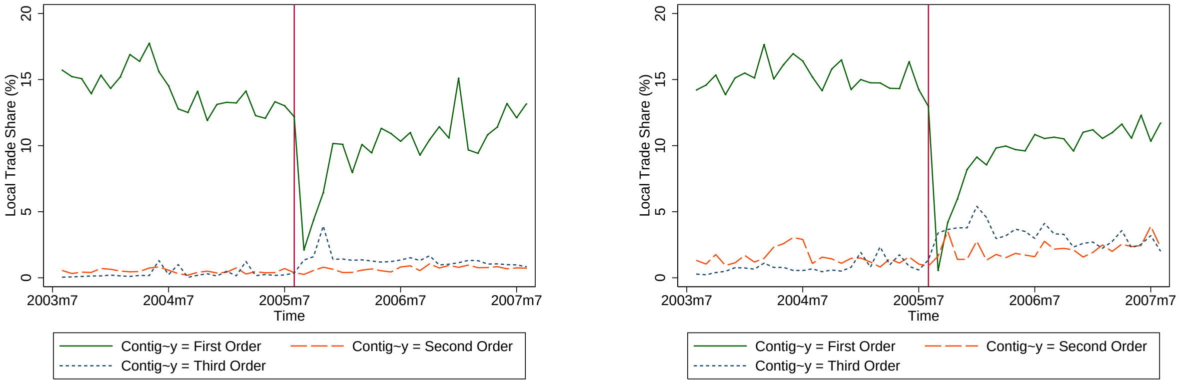
Katrina on regional U.S. imports, where we observe very slight reductions in the U.S. Gulf Coast and no visible effects on the Lower Atlantic or other regions.



(a) National Exports (b) National Imports



(c) Regional Export (d) Regional Imports

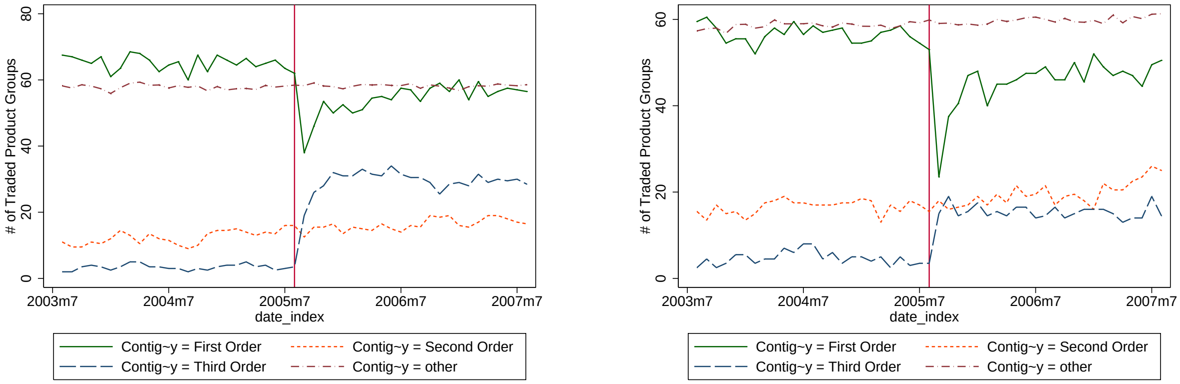


(e) Local Exports (f) Local Imports

FIGURE 12. Trends in Aggregate, Regional and Local U.S. Exports and Imports

Given these mixed findings at the regional level, a visual representation of the disaster induced trade disruptions at the local level is offered by Figures 12e and 12f. Again, the timing of Hurricane Katrina is given by the vertical red line, but now marks a point of significant disruptions regarding local export and import trade shares across the more narrowly defined first, second and third order contiguous ports located in the U.S. Gulf Coast and Florida. Indeed, Figures 12e and 12f provide supporting evidence that natural disasters cause negative trade disruptions at the immediately affected ports, whereas positive trade effects are encountered by ports with close proximity. Interestingly, the depicted trade time paths post Hurricane Katrina further suggest that the recovery of local trade is much slower than indicated by regional or national comparisons. While exports appear to recover to pre-disaster levels within the first two years, import trade shares exhibit long-lasting positive and negative trade disruptions.

Uncovering this initial evidence concerning the spatial and time heterogeneity of disaster induced trade effects, raises the question of the specific mechanisms driving the prolonged recovery of local trade. To this end, I provide Figures 13a and 13b which depict the number of two-digit HS traded product groups pre and post Hurricane Katrina. Both figures reveal dramatic and long-lasting reductions in the number of imported and exported products at the first order contiguous ports which coincide with a significant and permanent increase in the number of exported and imported products at the third order contiguous ports. Complementing the spatial heterogeneity in trade effects, second order contiguous ports, however, reveal no visual treatment effects concerning the number of traded products. In line with the negligible aggregate trade effects, higher order contiguous ports exhibit no change concerning their average trade composition in response to this natural disaster. These observations offer an first insights into port-specific the short-run and long-run recovery of local trade and suggest that both the local



(a) Exports

(b) Imports

FIGURE 13. Trends in the Number of Traded Products

patterns and composition of trade are subject to caused by natural disasters. Overall, this summary of the data provides strong preliminary evidence of the spatial and dynamic heterogeneity of disaster induced trade effects and resilience of trade.

Results

In this section, I present the empirical findings obtained from a variety of analyses culminating in the estimation of the empirical model specification given by equation 4.4. Starting with the aggregate effects on U.S. trade, I show that Hurricane Katrina has had negligible average export and import treatment effects across all ports. Dissecting these insignificant treatment effects, shown in Table 16, at a more disaggregate level, I then turn towards an estimation differentiating regional effects across ports located in the U.S. Gulf Coast and Lower Atlantic from other U.S. regions. Still, the results, given in Table 17, provide insignificant trade effects at the regional level and point to the intraregional resilience of trade. Further investigating this resilience, I focus on the estimation of local trade disruptions and turn towards a more flexible model that allows for port-specific short-run, medium-run or long-run treatment effects provided in Table 18. This analysis provides strong supporting evidence for localized trade disruptions and their systematic spatial heterogeneity.

Having obtained these port-specific average treatment effects, I provide potential explanations for their specific spatial distribution. To this end, I estimate the effects of port characteristics on these local disruptions. While both import and export disruptions depend on the distance to Hurricane Katrina, only the rerouting of exports exhibits dependence on port characteristics, such as harbor type or entry restrictions. Given this predominant role of distance in explaining the static resilience of trade, I further develop this analysis by estimating the variation in trade disruptions over nautical distance to Katrina's epicenter. The marginal effects obtained from these regressions are presented in Figures 14a-14d. In addition to these static estimations of spatial trade effects, I also present the dynamic results providing evidence of both long-run recovery and permanent treatment effects for some of the first to sixth order contiguous ports relative to Hurricane Katrina's epicenter. Concluding this section, I explore the main drivers of the unexpected permanent long-run effects and estimate trade disruptions for individual product categories. The results show that the port-specific change in the number of handled products exhibits industry-specific path dependencies and is mainly driven by trade in textiles.

Aggregate Analysis

Most of these analyses are based on the respective export and import estimations using the Poisson Pseudo-Maximum Likelihood (PPML) estimator, standard in the trade literature (Santos Silva and Tenreyro, 2006), and a variety of spatial econometric specifications, including the SAR, SEM and SAC models. The primary spatial results are based on a third order contiguity weight matrix, as discussed by Ord (1975), LeSage and

TABLE 16. Aggregate Trade Disruptions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	PPML		**SAR**		**SEM**		**SAC**	
VARIABLES	Export	Import	Export	Import	Export	Import	Export	Import
Hurricane Katrina	-0.012 (0.019)	-0.040 (0.029)	0.307 (0.261)	-0.076 (0.133)	0.287 (0.238)	-0.074 (0.129)	0.297 (0.249)	-0.075 (0.131)
Observations	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
R-squared	0.987	0.995	0.006	0.002	0.006	0.002	0.006	0.002
Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No	No	No	No
Spatial-Weighting	None	None	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order
Convergence	yes	yes	yes	yes	yes	yes	yes	yes

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

Pace (2009) or Getis (2009), for example, while a host of robustness analyses point to the consistency of the results across estimations involving alternative weight matrices, such as 1st order contiguity or inverse distance, for example. The aggregate effects are presented in Table 16 and match the findings of the previous literature (Parsons, 2014). Controlling for a time trend, port specific fixed effects and seasonal variation, I find that Hurricane Katrina has a statistically insignificant average impact across the major U.S. ports of entry and exit included in this sample. This negligible effect is consistent across the PPML and spatial estimators as well as exports and imports and is robust to alternative weight matrix specifications.[11]

Turning towards the regional analysis, I find similarly insignificant results for the U.S. coastal regions closest to Hurricane Katrina's epicenter. Table 17 provides treatment

---

[11] See Table 31 in Appendix C. While columns (1)-(6) of Table 31 present the export and import trade effects based on spatial weighting involving contiguity matrices of orders 1, 2 and 4, columns (7) and (8) depict the results obtained with an inverse distance weighting matrix. The port-to-port distances underlying this inverse distance weight matrix are presented in Table 30 of Appendix C.

TABLE 17. Regional Trade Disruptions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	PPML		**SAR**		**SEM**		**SAC**	
VARIABLES	Export	Import	Export	Import	Export	Import	Export	Import
Gulf Coast	0.056	-0.008	0.270	0.145	0.201	0.147	-0.213	0.145
	(0.088)	(0.136)	(0.237)	(0.410)	(0.241)	(0.388)	(1.223)	(0.418)
Lower Atlantic	0.023	0.035	1.202	0.645	0.946	0.592	1.450	0.646
	(0.059)	(0.047)	(0.936)	(0.492)	(0.808)	(0.447)	(1.819)	(0.526)
Observations	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
R-squared	0.988	0.996	0.011	0.007	0.011	0.007	0.016	0.007
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	None	None	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order
Convergence	yes	yes	yes	yes	yes	yes	yes	yes

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

effect estimates that differentiate the average trade disruptions experienced by ports located in the U.S. Gulf Coast and Lower Atlantic regions relative to ports located in all other U.S. coastal regions. In line with previous findings, columns (1) through (8) display statistically insignificant results for both regions across all export and import estimations. That is, controlling for port and time specific fixed effects, Hurricane Katrina appears to have had no discernibly different impact on trade across the U.S. Gulf Coast and Lower Atlantic regions relative to all others. Again, this finding is robust to variations in weight matrix specifications across all spatial econometric models.[12]

---

[12] See Table 32 in Appendix C.

Static Local Analysis

Based on the previous summary of the data, the insignificant regional findings come at no surprise. Instead, these results speak to the intraregional resilience of international trade offsetting local port trade reductions through immediate rerouting of traded goods to nearby and within region facilities with available capacity. To better understand the dependence of the disaster induced trade effects on port proximity to the epicenter of a natural disaster, I reestimate the model at a more disaggregated level. For this analysis I adapt the spatial autoregression model to inlcude port-specific export and import treatment effects across various time horizons. While columns (1) and (2) of Table 18 display the estimated trade disruptions averaged over three months post Hurricane Katrina's landfall, columns (3) and (4) as well as (5) and (6) present average treatment effects over two and eight years post disaster, respectively.

TABLE 18. Port-Specific Trade Disruptions

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
Seattle, WA	0.070***	0.026***	0.042***	-0.055***	-0.169***	-0.048***
	(0.004)	(0.000)	(0.002)	(0.002)	(0.015)	(0.001)
Portland, OR	-0.375***	-0.004***	-0.247***	0.378***	-0.406***	0.240***
	(0.002)	(0.001)	(0.004)	(0.002)	(0.019)	(0.001)
Oakland, CA	0.025***	0.011***	0.073***	-0.003	0.121***	0.044***
	(0.000)	(0.002)	(0.007)	(0.003)	(0.030)	(0.002)
Richmond, CA	-0.134***	-0.450***	0.287***	-0.663***	0.747***	-0.154***
	(0.000)	(0.001)	(0.006)	(0.002)	(0.022)	(0.001)
San Francisco, CA	**1.405*** **	**-1.129*** **	-0.180***	-0.174***	-0.674***	0.229***
	(0.007)	(0.002)	(0.007)	(0.003)	(0.031)	(0.002)
Port Hueneme, CA	**1.050*** **	**-1.200*** **	0.936***	**-1.043*** **	**1.308*** **	-0.672***
	(0.004)	(0.003)	(0.003)	(0.001)	(0.019)	(0.001)
Los Angeles, CA	-0.016	-0.143***	0.167***	-0.005***	0.103*	0.084***
	(0.027)	(0.015)	(0.006)	(0.002)	(0.055)	(0.000)
Long Beach, CA	0.184***	-0.095***	0.227***	-0.020***	0.179***	-0.043***
	(0.026)	(0.014)	(0.005)	(0.001)	(0.049)	(0.000)
San Diego, CA	-0.172***	0.501***	-0.452***	0.605***	-0.743***	0.328***
	(0.021)	(0.012)	(0.007)	(0.001)	(0.058)	(0.000)
Chicago, IL	0.148***	-0.204***	0.209***	0.017***	**-2.435*** **	0.472***

Continued on next page

Table 18 – *Continued from previous page*

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
	(0.007)	(0.008)	(0.002)	(0.006)	(0.027)	(0.012)
Port Huron, MI	0.195***	-0.316***	-0.294***	-0.076***	-0.000	0.048***
	(0.006)	(0.007)	(0.004)	(0.004)	(0.043)	(0.008)
Detroit, MI	-0.004	-0.169***	-0.007**	0.138***	-0.737***	0.297***
	(0.005)	(0.006)	(0.003)	(0.004)	(0.021)	(0.007)
Portland, ME	0.084***	0.690***	-0.327***	**-1.461*****	**-1.954*****	**-4.020*****
	(0.006)	(0.003)	(0.006)	(0.000)	(0.003)	(0.001)
Boston, MA	0.260***	-0.186***	0.285***	0.113***	0.060***	0.280***
	(0.006)	(0.000)	(0.005)	(0.006)	(0.007)	(0.005)
New York, NY	0.113***	-0.161***	0.252***	-0.033***	0.303***	0.289***
	(0.006)	(0.000)	(0.007)	(0.005)	(0.007)	(0.004)
Newark, NJ	0.198***	-0.130***	0.368***	-0.003	0.351***	0.151***
	(0.005)	(0.000)	(0.008)	(0.005)	(0.017)	(0.004)
Perth Amboy, NJ	0.120***	**-2.211*****	0.490***	**-1.469*****	0.730***	0.998***
	(0.005)	(0.004)	(0.010)	(0.000)	(0.030)	(0.001)
Philadelphia, PA	0.198***	-0.144***	0.342***	0.173***	0.177***	0.193***
	(0.005)	(0.002)	(0.010)	(0.003)	(0.035)	(0.002)
Chester, PA	0.230***	-0.190***	0.512***	0.050***	0.371***	0.159***
	(0.003)	(0.001)	(0.010)	(0.002)	(0.038)	(0.003)
Baltimore	0.085***	-0.103***	0.192***	0.073***	0.149***	0.197***
	(0.003)	(0.001)	(0.010)	(0.002)	(0.036)	(0.002)
Newport News, VA	0.176***	-0.033***	0.214***	0.048***	0.140***	0.091***
	(0.004)	(0.005)	(0.009)	(0.001)	(0.035)	(0.002)
Wilmington, NC	0.654***	0.015***	0.307***	0.276***	0.790***	0.893***
	(0.012)	(0.004)	(0.007)	(0.001)	(0.030)	(0.001)
Charleston, SC	0.044***	-0.087***	0.085***	-0.003***	-0.140***	0.026***
	(0.009)	(0.004)	(0.007)	(0.001)	(0.037)	(0.001)
Savannah, GA	0.129***	0.062***	0.333***	0.208***	0.522***	0.522***
	(0.009)	(0.004)	(0.006)	(0.002)	(0.030)	(0.002)
Brunswick, GA	**-1.252*****	-0.381***	-0.291***	-0.749***	0.225***	**-1.051*****
	(0.003)	(0.005)	(0.009)	(0.000)	(0.035)	(0.000)
Jacksonville, FL	0.233***	-0.258***	0.270***	0.124***	0.300***	0.538***
	(0.012)	(0.004)	(0.006)	(0.003)	(0.027)	(0.004)
Palm Beach, FL	0.236***	-0.229***	0.294***	-0.419***	0.001	-0.911***
	(0.013)	(0.004)	(0.007)	(0.001)	(0.033)	(0.000)
Port Everglades, FL	0.232***	0.039**	0.324***	-0.001	0.224**	-0.094***
	(0.032)	(0.019)	(0.043)	(0.007)	(0.104)	(0.005)
Miami, FL	-0.001	-0.200***	-0.037	-0.184***	-0.340***	-0.191***
	(0.038)	(0.022)	(0.048)	(0.010)	(0.115)	(0.008)
Corpus Christi, TX	**-4.999*****	**3.984*****	-0.269***	**2.332*****	**2.894*****	**1.387*****
	(0.004)	(0.005)	(0.004)	(0.000)	(0.024)	(0.001)
Houston, TX	0.106***	0.058***	0.310***	0.148***	0.320***	0.239***
	(0.032)	(0.004)	(0.006)	(0.002)	(0.040)	(0.005)
Freeport, TX	0.218***	-0.647***	0.131***	-0.796***	-0.101**	-0.654***
	(0.021)	(0.019)	(0.008)	(0.003)	(0.046)	(0.002)
Galveston, TX	0.942***	-0.192***	-0.088***	0.250***	0.479***	0.475***
	(0.030)	(0.011)	(0.008)	(0.000)	(0.040)	(0.004)

Continued on next page

Table 18 – *Continued from previous page*

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
Port Arthur, TX	**1.232*****	-0.175***	**1.728*****	**-1.515*****	0.145***	**-2.980*****
	(0.015)	(0.007)	(0.003)	(0.003)	(0.029)	(0.001)
Tampa, FL	-0.149***	-0.118***	0.373***	0.389***	0.177*	0.867***
	(0.032)	(0.017)	(0.043)	(0.007)	(0.102)	(0.005)
Panama City, FL	**10.512*****	**5.369*****	**10.566*****	**5.236*****	**10.133*****	**5.034*****
	(0.019)	(0.005)	(0.005)	(0.002)	(0.027)	(0.000)
Mobile, AL	0.045	0.341***	0.480***	0.406***	**1.070*****	**1.060*****
	(0.029)	(0.009)	(0.046)	(0.004)	(0.094)	(0.002)
New Orleans, LA	**-1.273*****	**-2.043*****	**-0.078***	**-0.487*****	**-0.149**	**0.003**
	(0.039)	(0.017)	(0.048)	(0.006)	(0.108)	(0.003)
Gulfport, MS	**-1.387*****	**-1.908*****	**-0.695*****	**-0.787*****	**-1.104*****	**-0.728*****
	(0.035)	(0.017)	(0.051)	(0.007)	(0.114)	(0.005)
Observations	1,120	1,120	1,960	1,960	4,840	4,840
R-squared	0.907	0.863	0.900	0.855	0.825	0.829
Random Effects	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order
Convergence	yes	yes	yes	yes	yes	yes

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

With respect to the excluded port of Tacoma, WA, nearly all treatment effects are statistically significant at the 1% level regardless of the time horizon under consideration and speak to the considerable month-to-month seasonal volatility and port-to-port variation observed in the trade data. While their statistical significance is largely invariant across ports, point estimates of the short to long-run average treatment effects exhibit large systematic variation. Albeit some natural outliers among the forty sample ports, such as Port Hueneme, CA or Portland, ME, Table 18 shows that those ports closer to Hurricane Katrina's epicenter tend to experience the largest short-run trade disruptions.[13] Specifically, both the port of Gulfport and New Orleans, the ports closest to Katrina's epicenter, reflect considerable short-run reductions in both exports and imports ranging from 72% to 87%. While these short-run effects are consistent for both ports, their

---

[13] For the ease of comparison, the parameters of interest are bold-faced and highlighted.

persistence varies. The port of New Orleans, for example, experiences a more rapid recovery relative to Gulfport. This recovery leads to significant reductions in absolute treatment effects over the medium to long-run and ultimately insignificant reductions in trade eight years post Hurricane Katrina. In contrast, Gulfport experiences incomplete recovery leading to statistically significant long-run trade reductions of 67% and 52% for exports and imports, respectively, relative to pre-treatment levels.

Extending the scope just beyond the hurricane warning zone, as depicted in Figures 10 and 11, the port of Panama City experiences the largest positive short-run trade disruptions out of any sample port. Point estimates range from 5.369 to 10.512 for imports and exports, respectively. Equally important is the fact that these estimated treatment effects stay relatively constant and statistically significant when extending the sample to the medium and long-run. The suggested permanence of these disaster-induced trade effects could speak towards the substantial switching costs for carriers choosing their ports of entry and exit and the resulting path dependence. Interestingly, the port of Mobile exhibits an insignificant export treatment effect and statistically significant, but relatively small increase in imports in the short-run. However, when considering the medium to long-run, these estimated treatment effects increase and become statistically significant for both exports and imports. An intuitive explanation for this initially surprising finding may be the fact that this port was located within the hurricane warning zone. Albeit being sparred from considerable damage, carriers may have avoided the entire hazard zone, including the port of Mobile, in the short-run. In the medium to long-run, however, the port's proximity to the severely damaged infrastructure of New Orleans and Gulfport, in particular, may have swayed carriers to consider the port of Mobile as a low-cost alternative.[14]

---

[14] In general, the port-specific results are qualitatively and quantitatively very consistent when estimated via the SAC model. The results of this robustness check are presented in Table 33 in Appendix C.

To address the evidenced short-run to long-run spatial heterogeneity in trade effects and gain a better understanding of the underlying factors driving the indicated resilience of international trade and persistence in trade effects, I conduct an additional analysis regressing the previously estimated port-specific treatment effects on time-invariant port characteristics and inverse distance. To gain insights into the selection of ports for rerouting carriers, I restrict the analysis to include only those treatment effects that are obtained for ports outside of the hurricane warning zone, excluding Gulfport, New Orleans and Mobile from the sample. The available characteristics include harbor type as well as tidal and other entry restrictions. The legend key to these characteristics is given by Table 34 in Appendix C and shows that the respective reference groups are *coastal breakwater* ports for the available harbor types and ports without any tidal or other entry restrictions. Given these reference groups, negative point estimates on any port characteristics imply that the presence of entry restrictions and specific harbor types other than coastal breakwater reduce the positive disaster induced treatment effects. Inverse distance is calculated as the 1/(nautical distance to Katrina's epicenter), as presented in Tables 14 and 15, so that a positive coefficient implies that closer ports experience exponentially larger treatment effects.

The results presented in Table 19 are quite interesting. That is, regardless of the time horizon under consideration, export treatment effects tend to be much more sensitive to the harbor type and entry restrictions than import treatment effects. In fact, the statistically significant negative point estimates suggest that almost all harbor types are less preferred relative to coastal breakwater ports when it comes to redirecting U.S. containerized exports. Carriers rerouting U.S. containerized imports, on the other hand, only seem to avoid *lake and canal* ports with a statistical significant impact only for the medium to long-run treatment effects. Similarly, carriers facilitating rerouted exports tend to avoid ports with tidal and other entry restrictions, particularly in the short-run, while these entry restrictions seem to have little influence on a carrier's port choice when rerouting imports.

TABLE 19. Influence of Port Characteristics on Treatment Effects

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
HT (=1)	**-1.648***	0.094	**-1.589****	-0.111	**-1.638****	-0.430
	(0.889)	(0.527)	(0.672)	(0.528)	(0.692)	(0.569)
HT (=2)	-0.531	0.266	-0.463	0.266	**-3.231*****	0.394
	(0.375)	(0.370)	(0.281)	(0.403)	(0.385)	(0.423)
HT (=3)	-1.803	-1.342	-1.743	**-2.866*****	**-3.750****	**-4.706*****
	(1.679)	(0.827)	(1.445)	(0.855)	(1.359)	(0.920)
HT (=4)	**-0.957***	0.009	**-0.870***	-0.077	**-1.071****	-0.259
	(0.546)	(0.409)	(0.448)	(0.446)	(0.503)	(0.477)
HT (=5)	**-1.063***	-0.326	**-1.101****	-0.188	**-1.208****	0.041
	(0.571)	(0.447)	(0.475)	(0.478)	(0.514)	(0.497)
HT (=6)	**-2.685***	-0.939	**-2.869****	-1.036	**-3.252****	-1.315
	(1.522)	(0.762)	(1.309)	(0.791)	(1.238)	(0.852)
ER - Tide	**-0.793***	-0.009	-0.657	-0.303	**-0.764***	**-0.846***
	(0.458)	(0.323)	(0.397)	(0.343)	(0.406)	(0.452)
ER - Other	**-1.790***	-0.404	**-1.412***	-0.172	-0.792	0.137
	(1.048)	(0.550)	(0.792)	(0.459)	(0.742)	(0.645)
Inv. Distance	1,278.532	**888.297****	**1,518.094****	**868.057****	**1,681.201****	**893.954****
	(836.505)	(381.456)	(720.448)	(378.613)	(659.917)	(396.400)
Observations	37	37	37	37	37	37
R-squared	0.415	0.451	0.613	0.503	0.637	0.536
Std. Errors	Robust	Robust	Robust	Robust	Robust	Robust

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

In contrast to the varying responses of export and import treatment effects with respect to port characteristics, both types of treatment effects are dependent upon the proximity of a given port. With the exception of the estimated short-run export disruptions, the inverse of nautical distance to the epicenter has a statistically significant positive impact on all export and import treatment effects. This, of course, translates into an exponential decline of the port-specific treatment effects in absolute distance; a finding that is increasingly pronounced in the medium and long-run. Both of these findings are quite intuitive. In the short-run, distance may not be as important of a factor as available capacity to handle rerouted trade immediately. Carriers may travel considerable distances to avoid being delayed and incur penalties. In the long-run, however, capacity could potentially be available at any port, so that distance becomes a more prominent factor in the determination of port choice, particularly when transport costs are an exponential function of this factor.

To further explore this dependence on distance, offer insights for both positive and negative treatment effects alike and gain a better understanding of potential differences in this distance dependence across export and import treatment effects, I develop and estimate a model interacting intraregional port groups with the inverse of nautical distance to Hurricane Katrina's epicenter averaging treatment effects over two years post Hurricane Katrina. For the purposes of this estimation, I differentiate between *core* and *peripheral* ports. The *core* is defined as those ports with first order contiguity to Hurricane Katrina' epicenter, while the *periphery* is defined as those ports located at greater orders of contiguity but still within the Gulf Coast and Lower Atlantic regions.[15] The estimation includes the traditional PPML estimator and spatial SAR, SEM and SAC models. The point estimates obtained from these regression analyses are presented in Table 36 of Appendix C and illustrate the statistically significant dependence of core and periphery treatment effects on distance. Based on these point estimates, Figures 14a through 14d illustrate the converted marginal export and import treatment effects for core and peripheral ports across distance for each of the respective models.[16]

---

[15] Since the port of Mobile, AL is located within the hurricane warning zone, but is yet a 2nd order contiguous port, it is unclear whether to consider this port as part of the core or periphery and it is, thus, excluded from this analysis. While their statistical significance suffers when including this port, point estimates vary only slightly.

[16] The conversion of the core and periphery point estimates into percentage changes in the value of trade is based on the following calculations: $\Delta\%Core = (exp(\beta_{core}) * exp(\beta_{core-dist.} * (1/(Distance)) - 1) * 100$ and $\Delta\%Periphery = (exp(\beta_{periphery}) * exp(\beta_{periphery-dist.} * (1/(Distance)) - 1) * 100$, respectively.

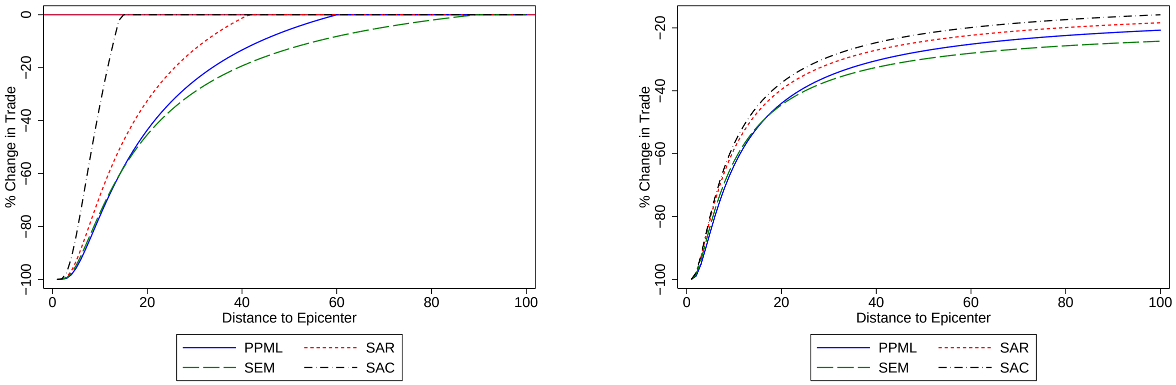
Several key features of these graphs are important to point out. While the estimated percentage changes for core ports are similar near the epicenter across all models, correction for spatial correlations leads to diverging estimates as distance increases. Concerning peripheral ports, the adjustment for potential spatial correlation leads to significantly larger treatment effects in close proximity to Hurricane Katrina's epicenter and a much steeper decline of these effects as distance increases relative to the PPML estimates. Although the estimated peripheral changes appear very large, the underlying differences in average pre and post port throughput listed in Tables 14 and 15 are also quite substantial. Rerouting of traded products away from a fairly large port, like New Orleans, can result in dramatic throughput changes in smaller nearby ports, like Panama City, which exhibits a 198 fold, or in other words roughly 19000%, increase in average exports post Hurricane Katrina.[17]

Overall the graphs show that the core ports experience economically significant export and import declines, although the reduction in exports is estimated to decay much faster over distance than the reduction in imports. That is, while trade handled by Gulfport, 15.7 nautical miles east of Katrina's epicenter, for example, is estimated to experience a 45.5% average reduction in exports and 45.0% average reduction in imports, the average trade effects at the port of New Orleans, 40.4 nautical miles west of Katrina's epicenter, for example, are estimated to yield only a 1.0% reduction in exports, but a 27.0% reduction in imports.[18] Treatment effects of the peripheral ports also reflect the expected patterns. That is, ports of close proximity to the epicenter experience larger

---

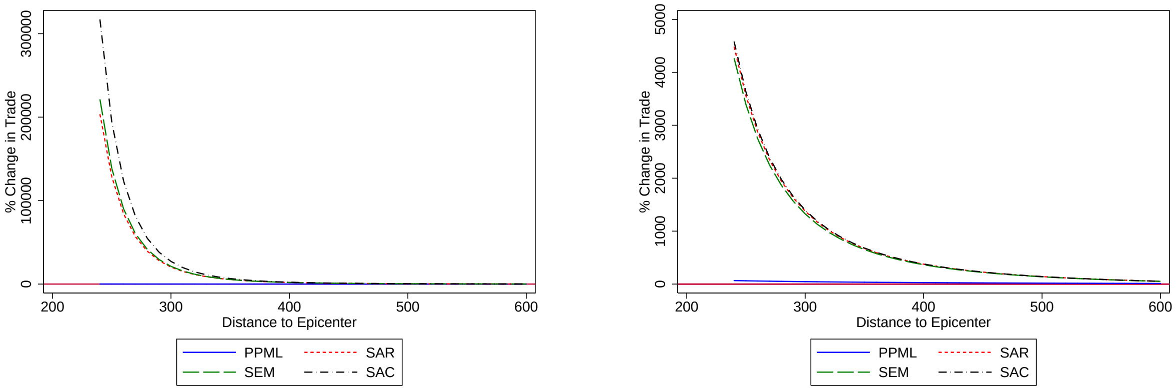
[17] A natural concern is the feasibility of such staggering increases and whether a port, like Panama City, can handle such shipments. The answer to this pressing question, lies within the presence of large sporadic pre-treatment shipments as evidenced by Panama City, FL prior to Hurricane Katrina. Although these shipments are large and require sufficient capacity, their sporadic nature implies little influence on pre-treatment average port throughput. Thus, Panama City appears as a small port, but with considerable excess capacity prior to Hurricane Katrina, capable of handling tremendous short-run increases.

[18] Calculations are based on the point estimates obtained from the SAR model.



(a) Exports - Core

(b) Imports - Core



(c) Exports - Periphery

(d) Exports - Periphery

FIGURE 14. Treatment Effects over Distance

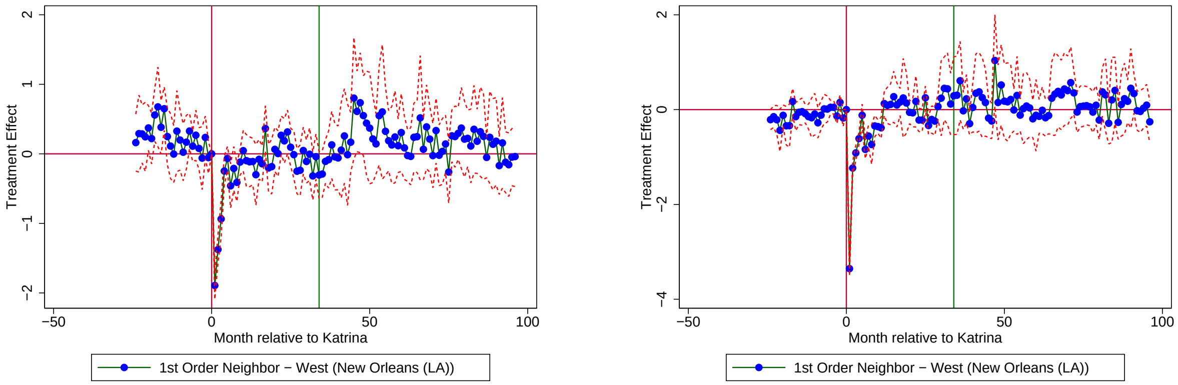
gains in trade than those ports at greater distances. Similarly to the marginal effects on trade handled by core ports, increases in exports decay at a faster rate over distance than increases in imports. That is, a peripheral port at a distance of roughly 400 nautical miles, such as Tampa, FL, experiences a 1957.0% increase in exports and 375.0% increase imports, while a port at a distance of roughly 700 nautical miles, such as Miami, FL, experiences only a 7.2% increase in exports, but 10.9% increase in imports. The fact that export trade disruptions are estimated to be more sensitive to distance than imports is intuitive. Imported containers are facilitated on container vessels that incur lower costs per mile traveled than exported containers that have to be rerouted via rail or trucking, both commanding much higher rates per mile than container vessels.

Dynamic Local Analysis

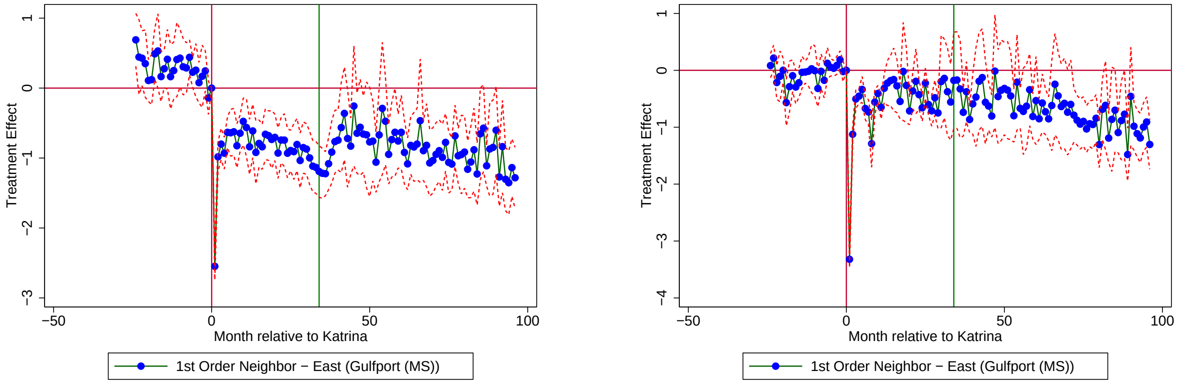
Having provided considerable evidence in support of the static local resilience of international trade and some preliminary evidence supporting its dynamic resilience, I now turn towards the primary estimation of the dynamic and spatially heterogeneous trade effects induced by Hurricane Katrina. To this end, I estimate the empirical specification given by equation (4.4) over the entire sample period, $R = 24$ and $S = 96$. Given the preliminary port-specific short-run to long-run treatment effects presented in Table 18, I focus this discussion around the ports closest to Hurricane Katrina, including Gulfport, New Orleans, Mobile and Panama City.[19] Since a tabular representation of these dynamic trade disruptions is quite convoluted, I use graphical representations of the estimated port-specific treatment effects instead. Figures 15a through 17b display port-specific time fixed effects in relation to August, 2005, the landfall of Hurricane Katrina. The vertical red line at 0 indicates this landfall, while the green vertical line at a value of 34 month post treatment indicates June, 2008, the midst of the *Great Trade Collapse (GTC).* Both of these vertical lines are included to aid in an additional comparison between the local trade disruptions of Hurricane Katrina and the GTC between 2008 and 2009 and help put the magnitude of these localized disaster effects into perspective. Given the empirical specification, each point on the graph can be thought of as a difference-in-differences estimator. That is, each point estimate post treatment reflects a month-port-specific treatment effect relative to that port's trade during the month of August, 2005,

---

[19] As part of the robust analysis, I also provide the dynamic treatment effects for ports at greater distances. The results are provided via Figures 18a through 25b and show no systematical treatment effects resulting from Hurricane Katrina.



(a) Exports - New Orleans, LA (b) Imports - New Orleans, LA



(c) Exports - Gulfport, MS (d) Imports - Gulfport, MS

FIGURE 15. Dynamic Variation in Treatment Effects - New Orleans, LA & Gulfport, MS

the time of Hurricane Katrina's landfall, and relative to the average change in trade across the excluded ports from August, 2005 to the given month under consideration. The flexibility of this specification allows for a clearer evaluation of the persistence of the disaster induced trade effects and facilitates dynamic cross port comparisons.[20]

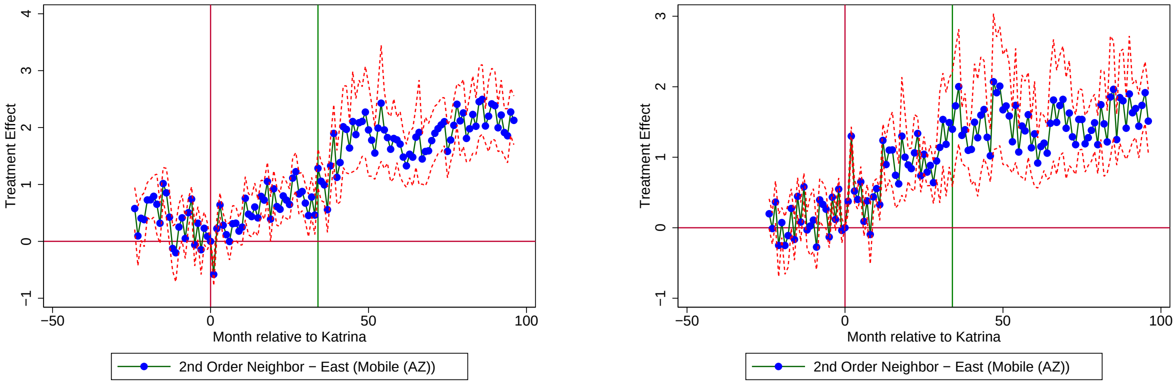
Figures 15a through 15d, for example, display tremendous short-run trade disruptions at the ports of New Orleans and Gulfport, but also reveal that the duration and magnitude of these disruptions vary across imports and exports as well as across the

---

[20] The presented trade effects are based on the SAR model and are robust to the use of the SEM or SAC models.

individual ports. For both ports, imports, for example, suffer a larger short-run reduction than exports. This finding is quite intuitive, given the fact that imports facilitated by container vessels are more easily rerouted than exports transported by train, truck or inland waterways. Relative to importing container vessels, these types of transportation modes are subject to significant rerouting barriers. This is particularly true for the port of New Orleans which is strategically located at the mouth of the Mississippi River and one of the main facilitator of bulk exports that have few transportation substitutes to the inland waterways. This route dependence of exports causes rather short-lived delays in export shipments and leads to smaller short-run export reductions.

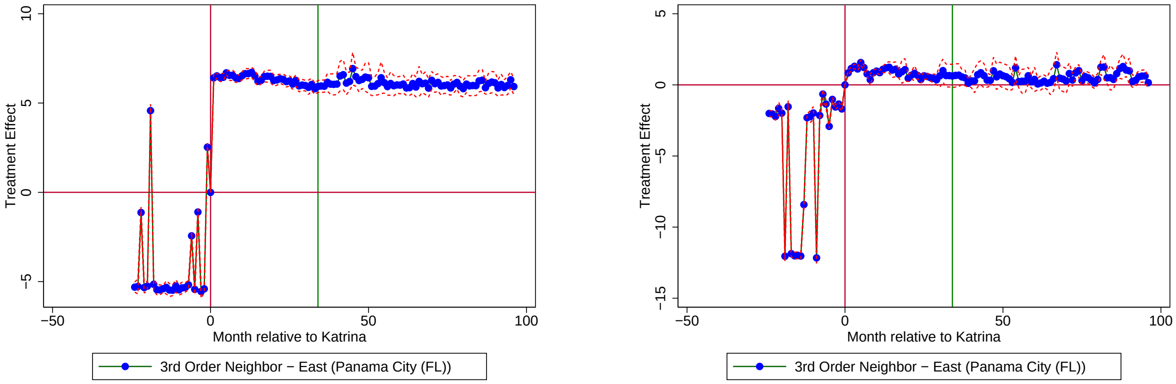
While these short-run export/import comparisons are similar for both ports, a long-run cross port comparison reveals that both exports and imports for the port of Gulfport experience rather lasting reductions relative to the port of New Orleans. In fact, while exports and imports handled by the port of New Orleans experience a rapid recovery over the first six month post treatment, depicted in Figures 15a and 15b, Gulfport's merely partial recovery is much more prolonged for both exports and imports, as shown by Figures 15c and 15d. These negative long-run effects can be traced back to the substantial damages sustained by the infrastructure at the port of Gulfport and documented by Grenzeback et al. (2008). Interestingly, these figures also illustrate that despite smaller short-run reductions, exports facilitated through Gulfport exhibit larger long-run effects than imports. A potential explanation for this amplified long-run response in exports may be the observable negative pre-treatment trend that was enhanced through Hurricane Katrina. Lastly, in the relation to the GTC, Figures 15a through 15d show that Hurricane Katrina had a much more severe localized short-run and even long-run impact on exports and imports than the GTC, raising the importance of a local trade analysis that can bring to light significant disruptions missed by aggregate estimations.



(a) Exports - Mobile, AL

(b) Imports - Mobile, AL

FIGURE 16. Dynamic Variation in Treatment Effects - Mobile, AL



(a) Exports - Panama City, FL

(b) Imports - Panama City, FL

FIGURE 17. Dynamic Variation in Treatment Effects - Panama City, FL

Expanding the spatial scope of the analysis, I now consider the dynamic trade effects of Hurricane Katrina on the ports of Mobile, AL and Panama City, FL. Both of these ports are just outside of the disaster stricken region and, as the previous static port-specific analysis suggests, are the primary candidates for the evaluation of the static and dynamic resilience of international trade. The results for both of these ports are presented in Figures 16a through 17b and illustrate significant short-run as well as long-run disruptions across both exports and imports. However, the depicted responses are very idiosyncratic across the two ports. While the short-run effects on Mobile exports suggest a one month significant reduction followed by a five month period of no change relative to pre-treatment export levels, the import trade effects at the port of Mobile are estimated to be positive and economically as well as statistically significant in the first two month following treatment before tapering off to pre-treatment levels over the next four month. Contrary to these opposing short-run responses, Figures 16a and 16b also reveal that both exports and imports facilitated through Mobile start experiencing positive growth roughly six to nine month post treatment. Again, these long-run effects vary across imports and exports. In the case of imports this growth merely matches the pre-treatment trend, while the growth in exports triggered by Hurricane Katrina is a reversal of a slightly negative pre-treatment trend. A potential explanation for this considerable change in the long-run growth rate of exports at the port of Mobile and reversal of the short-run reductions, is the pronounced long-run decline in exports experienced by the neighboring port of Gulfport.

In contrast to these varying and mild short-run responses as well as persistent growth rate changes of trade handled by the port of Mobile, exports and imports facilitated through the port of Panama City, depicted by Figures 17a and 17b, experience immediate and large increases in response to Hurricane Katrina that are very persistent in the long-run. While imports reveal a statically and economically significant increase post Hurricane Katrina, Panama City's exports reflect an unparalleled economically and statistically significant upward jump that persists through the entire sample period. Even during the GTC, these long-run responses of exports and imports remain effectively undisturbed.

Based on these estimated treatment effects across the ports of Gulfport, New Orleans, Mobile and Panama City, one can conclude that the static resilience of international trade and resulting negligible aggregate trade effects are mainly driven by rerouted exports and imports through the port of Panama City. Moreover, the estimates show that the dynamic resilience of international trade in response to Hurricane Katrina is driven by the long-run recovery by the port of New Orleans and the persistent long-run increases in exports and imports at the ports of Mobile and Panama City that offset the permanent reductions experienced by port of Gulfport.

In contrast to these consistent and considerable short-run and long-run trade effects displayed by the ports of Gulfport, New Orleans, Mobile and Panama City, ports located at greater distances show no identifiable response to Hurricane Katrina. In fact, Figures 18a through 25b in Appendix C provide no evidence of any short-term or long-term responses in exports or imports that are distinguishable from pre-hurricane variation or can be directly linked to Hurricane Karina. In summary, these findings suggest that albeit significant disaster induced reductions in trade for those ports closest to the epicenter, a transport network, similar to that of the U.S., can offset the majority of trade reductions caused by a natural disaster, similar to Hurricane Katrina, within a small geographic region. The indicated mechanisms of the resilience of trade include rerouting and delaying of traded products within a narrow band of nearby ports leaving short-run and long-run trade effects unaffected at the aggregate level.

Disaggregated Analysis

To gain a better understanding of the underlying forces driving these dynamic disruptions in the value of trade, I redirect the focus of the analysis towards the effects at a more disaggregated product level. Specifically, I consider the effects of Hurricane Katrina on the number of products facilitated by a given port differentiating across several different product categories. Reestimating the port-specific treatment effects over the short, medium and long-run on the number of traded products, I provide insights into the specific industries driving the static and dynamic resilience of international trade. Similar to the dynamic analysis, the results reported here focus on the primary ports of interest including Gulfport, New Orleans, Mobile and Panama City and are summarized in Tables 20 and 21 for exports and imports, respectively.[21]

The number of traded products for a given port-month pair is based on the 2 digit HS classification that consolidates individually traded products into 98 product groups. While column (1) of Tables 20 and 21 provides the treatment effects of Hurricane Katrina on the total number of traded products, columns (2) through (8) depict these trade effects for seven slightly more disaggregated product categories. The consolidation of the original 98 product groups into these seven product categories is based on sections and individual product group definitions obtained from Schedule B reported by the *U.S. Census Bureau.*[22] A legend providing the necessary details for each of these product categories is presented in Table 22. The estimation results at this disaggregated level are intended to disentangle the aggregate effects observed in column (1) and help identify whether the disaster induced trade disruptions are experienced across all industries or rather idiosyncratic.

When considering the aggregate effects on the number of traded products presented in column (1), it becomes clear that these results reflect the expected patterns. In the short-run, the ports of New Orleans and Gulfport experience economically and statistically significant reductions in the number of exported and imported products ranging from

---

[21] The remaining short-run to long-run port-specific treatment effects of ports located at greater distances have been estimated and the results are available upon request. As expected, the majority of these treatment effects for more remote ports are again statistically significant due to the large port-to-port and month-to-month volatility in trade, but without any significant outliers or discernible patterns relative to the primary ports under consideration.

[22] Schedule B is the official schedule of commodity classifications to be used by shippers in reporting export shipments from the United States.

TABLE 20. Port-specific Effects on the Number of Exported Products

Ports	(1) Total	(2) Category 1	(3) Category 2	(4) Category 3	(5) Category 4	(6) Category 5	(7) Category 6	(8) Category 7
Short-Run								
Panama City, FL	**47.781*****	-0.122***	3.335***	**9.587*****	**5.335*****	**12.768*****	**6.843*****	**8.326*****
	(0.316)	(0.032)	(0.038)	(0.003)	(0.011)	(0.040)	(0.061)	(0.005)
Mobile, AL	7.914***	-1.803***	0.427***	1.109***	1.038***	1.535***	2.556***	3.486***
	(0.101)	(0.029)	(0.015)	(0.058)	(0.014)	(0.044)	(0.042)	(0.042)
New Orleans, LA	**-15.534*****	**-4.985*****	-0.280***	-1.175***	-0.577***	**-4.548*****	-1.720***	-1.677***
	(0.456)	(0.006)	(0.007)	(0.082)	(0.025)	(0.110)	(0.013)	(0.110)
Gulfport, MS	**-15.661*****	-2.239***	-3.148***	-2.782***	-1.500***	**1.440*****	-3.744***	-2.770***
	(0.591)	(0.040)	(0.045)	(0.119)	(0.039)	(0.061)	(0.016)	(0.147)
Medium-Run								
Panama City, FL	**57.177*****	2.071***	**5.583*****	**11.947*****	**4.780*****	**14.939*****	**7.818*****	**9.759*****
	(0.097)	(0.002)	(0.003)	(0.030)	(0.005)	(0.004)	(0.006)	(0.014)
Mobile, AL	**12.343*****	-0.750***	0.962***	2.913***	0.597***	**5.239*****	2.892***	2.843***
	(0.509)	(0.013)	(0.031)	(0.081)	(0.029)	(0.050)	(0.044)	(0.054)
New Orleans, LA	**-8.206*****	**-2.480*****	0.086**	-0.468***	-1.012***	-0.491***	-0.249***	-0.733***
	(0.838)	(0.023)	(0.043)	(0.117)	(0.045)	(0.092)	(0.089)	(0.095)
Gulfport, MS	**-7.156*****	-1.566***	-0.450***	-0.497***	-1.149***	**3.297*****	-1.628***	-1.841***
	(0.960)	(0.014)	(0.054)	(0.140)	(0.048)	(0.084)	(0.125)	(0.125)
Long-Run								
Panama City, FL	**59.267*****	**3.254*****	**5.452*****	**12.081*****	**6.001*****	**14.511*****	**8.574*****	**9.228*****
	(0.319)	(0.010)	(0.039)	(0.041)	(0.017)	(0.042)	(0.024)	(0.022)
Mobile, AL	**15.751*****	0.835***	2.467***	2.642***	0.899***	**4.779*****	2.903***	2.245***
	(0.850)	(0.021)	(0.066)	(0.130)	(0.048)	(0.115)	(0.071)	(0.058)
New Orleans, LA	**-4.244*****	**-2.274*****	0.267***	-0.319	-0.283***	-0.265	-0.070	-0.402***
	(1.305)	(0.043)	(0.098)	(0.194)	(0.062)	(0.175)	(0.120)	(0.091)
Gulfport, MS	**-7.326*****	-1.750***	0.428***	-1.032***	-0.801***	**1.429*****	-1.996***	-2.368***
	(1.620)	(0.044)	(0.112)	(0.244)	(0.074)	(0.187)	(0.189)	(0.127)
Random Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order

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

15 to 31 lost product groups. Over time, however, these large initial reductions in the portfolio of traded products revert back towards pre-treatment levels. As expected, New Orleans experiences a more rapid recovery over the medium to long-run relative to the port of Gulfport. In the long-run the estimated treatment effects for New Orleans, for example, result in statistically significant reductions of the number of traded products by 4 and 6 for exports and imports, respectively, while Gulfport continues to suffer reductions of 7 to 10 exported and imported product groups.

Considering the adjacent ports, the estimated treatment effects on the aggregate number of traded products, once again, match the previous findings and provide supporting evidence of the static and dynamic resilience of trade. In the short-run the port of Panama City experiences substantial increases in the number of imported and exported products ranging from 23 to 47, respectively, while the port of Mobile only adds 1 additional product on the import side and 7 on the export side. Expanding the time horizon under consideration emphasizes the expected persistence of the positive gains in the portfolio of products handled by the port of Panama City and the considerable growth in the number of exported and imported products for the port of Mobile. That is, the estimated average treatment effects over the first eight years after Hurricane Katrina suggest a statistically significant and persistent increase in the number of exported and imported products by 59 and 27 for the port of Panama City and 16 and 18 for the port of Mobile, respectively.

At the disaggregated level, the port of New Orleans experiences a relatively even reduction in all of the seven imported product categories with point estimates ranging from 27% and 44% in the short-run. On the export side, however, we observe a very heterogeneous response concerning the number of traded products that is driven by decreases in Categories 1 (-33%) and 5 (-25%). This heterogeneity in treatment effects continues to persist for the number of exported products and also manifests itself for the number of imported products in the medium to long-run. While the number of traded products recovers over time and reverts to pre-treatment levels for the majority of product categories handled by the port of New Orleans, the remaining negative aggregate treatment effect is almost exclusively driven by permanent reductions in trade of *Animal and Vegetable Products*, shown in column (2) of Tables 20 and 21.

In contrast to New Orleans, the short-run effects for the port of Gulfport are fairly evenly spread across all imported and exported categories. The exception to this rule are textiles which experience a surprising increase in the number of exported products.[23] While this relatively even distribution of treatment effects persists in the medium to long-run for the number of exported products facilitated through Gulfport, the distribution of the trade disruptions becomes rather bimodal for the number of imported products. In particular, the estimates suggest that the sustained reduction in the number of imported products and incomplete overall long-term recovery appears to be mainly driven by the lack of imported *Animal and Vegetable products* and *Textiles*.

Turning the attention towards the positively affected ports of Panama City and Mobile, the estimated category-specific treatment effects suggest rather heterogeneous responses across industries. For Panama City, for example, all product categories but *Animal and Vegetable Products* reveal economically and statistically significant increases ranging from 37% to 71% in the short-run. In the medium to long-run, aggregate increases in the total number of exported products are predominantly driven by changes in categories 3 (*Mineral products, etc.*) and 5 (*Textiles*), which increase by 75% to 82%, respectively, while *Animal and Vegetable Products* continue to be a disproportionately small contributor to the increase in exported products. A similar pattern is observed on

---

[23] This surprising increase in the number of exported *Textiles* continues to be estimated even in the long-run.

TABLE 21. Port-specific Effects on the Number of Imported Products

Ports	(1) Total	(2) Category 1	(3) Category 2	(4) Category 3	(5) Category 4	(6) Category 5	(7) Category 6	(8) Category 7
Short-Run								
Panama City, FL	**23.927***	2.757***	-0.240***	0.282***	**3.074***	**9.135***	**3.429***	**3.785***
	(0.266)	(0.066)	(0.001)	(0.035)	(0.031)	(0.059)	(0.051)	(0.059)
Mobile, AL	0.609***	-0.405***	0.139***	-0.663***	0.384***	0.958***	0.181***	0.061
	(0.157)	(0.044)	(0.015)	(0.036)	(0.020)	(0.001)	(0.031)	(0.037)
New Orleans, LA	**-31.928***	**-4.317***	-2.567***	**-5.978***	**-3.182***	**-7.855***	**-3.999***	**-3.788***
	(0.081)	(0.001)	(0.013)	(0.004)	(0.003)	(0.098)	(0.001)	(0.006)
Gulfport, MS	**-15.751***	-1.886***	-0.108***	-2.888***	-1.881***	**-4.057***	**-3.226***	-1.812***
	(0.049)	(0.044)	(0.030)	(0.031)	(0.001)	(0.061)	(0.000)	(0.021)
Medium-Run								
Panama City, FL	**24.154***	**3.432***	1.178***	1.320***	2.900***	**7.796***	2.914***	**3.501***
	(0.058)	(0.035)	(0.003)	(0.002)	(0.009)	(0.003)	(0.000)	(0.000)
Mobile, AL	6.959***	-0.391***	1.148***	0.198***	0.497***	2.801***	1.695***	1.481***
	(0.113)	(0.015)	(0.005)	(0.007)	(0.000)	(0.042)	(0.014)	(0.021)
New Orleans, LA	**-12.890***	**-3.399***	-1.689***	-0.807***	-1.047***	-2.850***	-1.186***	-0.950***
	(0.383)	(0.010)	(0.026)	(0.014)	(0.011)	(0.106)	(0.043)	(0.049)
Gulfport, MS	**-10.621***	-1.991***	-0.298***	-1.568***	-0.909***	-2.183***	-1.960***	-0.952***
	(0.294)	(0.017)	(0.011)	(0.012)	(0.010)	(0.090)	(0.045)	(0.044)
Long-Run								
Panama City, FL	**27.493***	**4.358***	2.290***	1.301***	**3.592***	**8.187***	2.400***	**4.628***
	(0.217)	(0.025)	(0.022)	(0.014)	(0.002)	(0.108)	(0.013)	(0.040)
Mobile, AL	**17.805***	0.455***	2.259***	0.814***	1.934***	**6.569***	**3.256***	2.931***
	(0.384)	(0.005)	(0.030)	(0.018)	(0.006)	(0.151)	(0.013)	(0.064)
New Orleans, LA	**-6.392***	**-2.548***	-0.958***	-0.479***	0.316***	-0.797**	-0.093***	-0.747***
	(0.865)	(0.023)	(0.067)	(0.031)	(0.023)	(0.310)	(0.036)	(0.116)
Gulfport, MS	**-9.610***	**-3.014***	1.379***	-1.011***	-0.445***	-1.684***	**-3.166***	-0.648***
	(0.778)	(0.009)	(0.037)	(0.021)	(0.026)	(0.289)	(0.048)	(0.107)
Random Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order

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

the import side, where increases in the number of imported *Textiles* dominate the average changes of the product portfolio across all time horizons under consideration (43%-51%). The same holds true for the port of Mobile in the medium to long-run. *Textiles* are shown to be the main factor underlying Mobile's disaster induced export and import growth and the most prominent contributor to the changes in the local trade composition increasing by 27% and 36% in the long-run, respectively.

Overall, these results provide considerable insights into the previously described trade disruptions caused by Hurricane Katrina. While the static and dynamic resilience of trade is evidenced for both the value of trade and number of traded products, the product-specific contributions to these offsetting trade disruptions in the short-run and overall recovery in the long-run are very heterogeneous across industries. High value containers of *Textiles*, for example, tend to be very resilient types of trade, whereas containerized trade of *Live Animals and Vegetable Products* appears to be less resilient and suffers disproportionately large disruptions from natural disaster. Given the fact that origin and/or destination changes in containerized shipments of *Live Animals and Vegetable Products* are rather costly, due to the required special handling and equipment, relative to shipments of *Textiles*, this finding is quite intuitive.

Conclusion

The increasing presence and reliance of global economic output on international transactions has lead to the significant growth of international trade and its exposure to the omnipresent devastation caused by natural disasters. Frequent, yet uncertain calamities continue to cause tremendous human and economic hardship, but have been largely ignored in the trade literature. In the present study, I evaluate the impacts of Hurricane Katrina on U.S. trade and find that natural disasters represent significant

TABLE 22. Product Category Legend Key

Product Category	# of Products	Sections included	Type of Products
1	15	1-3	Animal and Vegetable Products
2	9	4	Prepared Food Stuffs, Beverages, Spirits, Tobacco, etc.
3	16	5-7	Mineral, Chemical, Rubber and Plastic Products
4	9	8-10	Wood and Paper and products thereof, Leather, etc.
5	18	11, 12	Textiles, Footwear, Umbrellas, etc.
6	15	13-15	Bulk products including Stone, Plaster and Base Metals
7	14	16-19, 21	Work of Art, Manufactured products (i.e. Vehicles, etc.)

Source: Schedule B published by the *U.S. Census Bureau*
Notes: Excluded products groups include special classification provisions

barriers to international trade at the local port level. In conjunction with negligible aggregate treatment effects, the estimated dynamic and spatially heterogeneous trade disruptions point to the static and dynamic resilience of international trade.

The mechanisms underlying this trade resiliency include considerable rerouting of both exports and imports and their rapid recovery due to product-specific path dependence that lead to statistically and economically significant gains in trade for those ports closest to the disaster stricken region and negatively disrupted ports. The local disruptions are shown to be port-specific, of temporary nature for some ports and permanent for others, heterogeneous across industries and offsetting in aggregate. While the rerouting of exports and imports is shown to strongly depend on the distance between the affected and non-affected ports, only rerouting of exports depends on port-specific characteristics, such as harbor type or entry restrictions. In conjunction, these empirical results illustrate the importance of a closely knit infrastructure network to mitigate aggregate repercussions resulting from natural disasters, even the ones as monumental as Hurricane Katrina. As developing countries continue to experience significant aggregate disruptions from natural disasters, the empirical evidence pertaining to the negating transport network effects of rerouting of internationally traded products are of considerable interest to global policy makers.

Interestingly, the empirical findings point to an east/west dichotomy concerning the significance and magnitude of the trade effects resulting from Hurricane Katrina. Further inquiry may consider the role of hinterland transportation networks and other infrastructure characteristics that drive this spatially heterogeneous response and resulting resilience of international trade.

CHAPTER V

CONCLUSION

The overarching theme of the research presented in the substantive chapters of this dissertation are the interconnections between trade and transportation. Exploring these interconnections, I have shown that transportation costs are not only an integral factor in the determination of trade, but also an endogenously determined component of these international transactions. Building on this simultaneity between trade and transportation, my work highlights the relevance of international transportation industries in the determination of trade and transport policy outcomes and the spatial distribution of trade disruptions stemming from natural disasters. Given the current political context as well as the considerable number of recent natural disasters, my findings are pertinent to numerous policy considerations and contribute to the economic literature across various subfields.

Chapter II contributes to the international and transportation economics literatures by developing a model that accounts for the simultaneity between trade and transportation and by providing novel empirical evidence of the co-integration underlying this endogeneity. Using advanced time-series techniques, I estimate the structural equations governing the long-run equilibrium between trade and transport costs across three major international markets. Adding to a growing strand of the international economics literature that considers various financial and supply chain spillovers in international markets, I use these estimates to offer insights into the transportation induced spillover effects arising from the joint determination of fronthaul and backhaul trade and transport costs.

While building on this research, Chapter III offers several additional contributions to the economic literature. Extending the theoretical framework, I illustrate that the previously highlighted integration of bilateral fronthaul and backhaul transport markets, in fact, depends on the balance of bilateral trade. Deriving several comparative statics, I illustrate the importance of this dependence in terms of policy outcomes. Empirical tests of the theoretical predictions provide novel evidence supporting the hypotheses that trade and transport policy outcomes systematically vary across fronthaul and backhaul transport markets, various levels of bilateral trade imbalances and differentiated product groups. Not only do these novel findings help explain otherwise unanticipated variation in policy outcomes, but they also have significant implications for current and future policy considerations, such as the Trade Facilitation Agreement by the WTO. Furthermore, linking the results to global trade patterns points to considerable implications concerning the potential trade effects across developing and developed countries, offers new insights into the source for potential policy outcome inequality across these types of countries, and raises a host of future research questions to be explored.

In contrast to the evaluation of trade and transport policy outcomes under an endogenously responding transport sector, my research presented in Chapter IV considers the influence of this sector in the determination of the short-run and long-run trade disruptions caused by natural disasters. More specifically, I evaluate the dynamic impact of Hurricane Katrina on trade at a disaggregated U.S. port level. The empirical results pertaining to the spatial distribution of the disaster induced trade effects point to offsetting short-run disruptions, dynamic recovery and some permanent trade route alterations. In doing so, these findings are the first to evidence the static and dynamic resilience of international trade. Exploring the underlying factors determining this resilience, I identify distance as the key variable of interest. The results show that the availability of excess port capacity in close proximity to a natural disasters is essential to overcome the incurred reductions in trade and highlight the importance of a sufficient infrastructure network. Overall, the findings suggest that aggregate analyses considering national trade effects are misleading and conceal the significant local disruptions caused by natural disasters.

Lastly, I would like to highlight a few of the related research questions arising from this work and acknowledge the significant influence it will have on shaping my future research agenda. Building on the results I have derived in Chapters II and III, I intend to further explore the connections between environmental policies and trade. More specifically, I plan to analyze the trade effects of the recently established Emission Control Areas in North America and Europe, while evaluating the potentially varying welfare implications across developed and developing countries. Secondly, I plan to empirically address the question of whether trade imbalances and the resulting freight rate differentials act as a dispersion force to the Home Market Effect and deter foreign direct investment. Finally, following the analysis provided in Chapter IV, I will further investigate the consequences arising from the local resilience of international trade. The underlying question considers whether the resilience of trade triggers a creative destruction effect in local communities proximate to but sparred by a given natural disaster.

In conclusion, it is my hope that the theoretical and empirical findings provided in this dissertation and my future work will be valued by and useful to researchers, policy-makers and practitioners alike and make a difference in the realm of international trade and transportation.

APPENDIX A

PROOFS

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 (3.13) shows that

$$\left|\frac{\partial q_{ij}}{\partial a_{ij}}\frac{a_{ij}}{q_{ij}}\right| = \sigma\frac{a_{ij}}{p_i\tau_{ij} + a_{ij}} > \sigma\frac{a_{ik}}{p_i\tau_{ik} + a_{ik} + JC'} = \left|\frac{\partial q_{ik}}{\partial a_{ik}}\frac{a_{ik}}{q_{ik}}\right|. \tag{A.1}$$

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 higher 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 (3.13) must be increasing in the domestic sales price, p_i:

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

APPENDIX B

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:

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

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

$$\frac{\partial x_{ij}}{\partial a_{ij}}\frac{a_{ij}}{x_{ij}} = (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} < 0 \text{ if } Q_{ij} = Q_{ji}, \tag{B.2}$$

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

$$\frac{\partial x_{ij}}{\partial a_{ij}}\frac{a_{ij}}{x_{ij}} = (1-\sigma)\frac{a_{ij}}{(p_i\tau_{ij} + f_{ij})}\frac{\partial f_{ij}}{\partial a_{ij}} = \begin{cases} (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}+JC'} < 0 & \text{if } Q_{ij} > Q_{ji} \quad (fronthaul) \\ (1-\sigma)\frac{a_{ij}}{p_i\tau_{ij}+a_{ij}} < 0 & \text{if } Q_{ij} < Q_{ji} \quad (backhaul). \end{cases} \tag{B.3}$$

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:

$$\frac{\partial x_{ij}}{\partial JC'}\frac{JC'}{x_{ij}} = (1-\sigma)\frac{JC'}{p_i\tau_{ij} + p_j\tau_{ji} + a_{ij} + a_{ji} + JC'} \text{ if } Q_{ij} = Q_{ji}, \tag{B.4}$$

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

$$\frac{\partial x_{ij}}{\partial JC'}\frac{JC'}{x_{ij}} = (1-\sigma)\frac{JC'}{(p_i\tau_{ij}+f_{ij})}\frac{\partial f_{ij}}{\partial JC'} = \begin{cases} (1-\sigma)\frac{JC'}{p_i\tau_{ij}+a_{ij}+JC'} & \text{if } Q_{ij} > Q_{ji} \quad \text{(fronthaul)} \\ 0 & \text{if } Q_{ij} < Q_{ji} \quad \text{(backhaul).} \end{cases} \tag{B.5}$$

A comparison between equation (3.12) and (B.2), (3.13) and (B.3), (3.14) and (B.4), as well as (3.15) and (B.5) 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. Interestingly, these theoretical derivations also suggest that the response in the value of trade is smaller than the response in the volume of trade, $|-\sigma| > |1-\sigma|$.

APPENDIX C

ADDITIONAL TABLES AND FIGURES

Chapter III Robustness Analyses

TABLE 23. 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**
ATE, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Treatment/Control	-0.045	-0.027	-0.085**	-0.044	-0.109**
Group Time Trends	(0.037)	(0.046)	(0.040)	(0.045)	(0.047)
Panel 3 - Country-Specific	-0.037	0.005	-0.078*	-0.038	-0.111**
Time Trends	(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 24. 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
ATE, (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 25. Robustness Analysis - Varying Fixed Effects Specifications

VARIABLES	(1) Fronthaul	(2) Backhaul	(3) Fronthaul	(4) Backhaul	(5) Fronthaul	(6) Backhaul	(7) Fronthaul	(8) Backhaul
ATE, (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 26. 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**
ATE, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Incl. Landlocked	-0.020	0.006	-0.088**	-0.018	-0.100**
European Countries	(0.032)	(0.039)	(0.040)	(0.038)	(0.045)
Panel 3 - Incl. North	-0.022	0.004	-0.092**	-0.019	-0.101**
American Countries	(0.032)	(0.039)	(0.039)	(0.038)	(0.045)
Panel 4 - Excl. China &	-0.048	-0.031	-0.093*	-0.062	-0.100*
Japan	(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 27. 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**
ATE, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Excl.	-0.025	-0.010	-0.083**	-0.021	-0.092**
U.S. State Employment	(0.033)	(0.042)	(0.040)	(0.040)	(0.047)
Panel 3 - Excl.	-0.031	-0.012	-0.083**	-0.029	-0.111**
U.S. FTAs	(0.034)	(0.041)	(0.040)	(0.040)	(0.049)
Panel 4 - Incl.	-0.041	-0.013	-0.086**	-0.029	-0.107**
Lagged Control Variables	(0.034)	(0.043)	(0.039)	(0.043)	(0.046)
Panel 5 -	-0.028	-0.005	-0.091**	-0.022	-0.117**
Aggregated Quarterly Data	(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 28. Robustness Analysis - Varying Backhaul Identifications

VARIABLES	(1) FH - Primary	(2) BH - Primary	(3) FH - Exp. Lag	(4) BH - Exp. Lag	(5) FH- Imp. Lag	(6) BH - Imp. Lag
ATE, (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 29. Robustness Analysis - BH 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**
ATE, (δ)	(0.033)	(0.041)	(0.040)	(0.040)	(0.045)
Panel 2 - Supranational	-0.054	-0.050	-0.078	-0.053	-0.098*
ATE, (δ)	(0.036)	(0.031)	(0.069)	(0.039)	(0.059)
Panel 3 - U.S. State -	-0.054	-0.050	-0.078	-0.043	-0.105**
Supranational	(0.033)	(0.032)	(0.048)	(0.036)	(0.045)
Panel 4 - U.S. Region -	-0.045*	-0.050	-0.078***	-0.068*	-0.096**
Supranational	(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

Chapter IV Robustness Analyses

TABLE 30. Distances between U.S. Ports of Entry

	Tacoma, WA	Seattle, WA	Portland, OR	San Francisco, CA	Richmond, CA	Oakland, CA	Port Hueneme, CA	Los Angeles, CA	Long Beach, CA	San Diego, CA
Tacoma	0									
Seattle	25	0								
Portland, OR	387	362	0							
San Francisco	1039	1014	652	0						
Richmond	1050	1025	663	11	0					
Oakland	1064	1039	677	25	14	0				
Port Hueneme	1379	1354	992	340	329	315	0			
Los Angeles	1441	1416	1054	402	391	377	62	0		
Long Beach	1444	1419	1057	405	394	380	65	3	0	
San Diego	1538	1513	1151	499	488	474	159	97	94	0
Corpus Christi	6000	5975	5613	4961	4950	4936	4621	4559	4556	4462
Freeport	6160	6135	5773	5121	5110	5096	4781	4719	4716	4622
Galveston	6244	6219	5857	5205	5194	5180	4865	4803	4800	4706
Houston	6291	6266	5904	5252	5241	5227	4912	4850	4847	4753
Port Arthur	6423	6398	6036	5384	5373	5359	5044	4982	4979	4885
New Orleans	6864	6839	6477	5825	5814	5800	5485	5423	5420	5326
Gulfport	7135	7110	6748	6096	6085	6071	5756	5694	5691	5597
Mobile	7233	7208	6846	6194	6183	6169	5854	5792	5789	5695
Panama City	7426	7401	7039	6387	6376	6362	6047	5985	5982	5888
Tampa	7691	7666	7304	6652	6641	6627	6312	6250	6247	6153
Miami	8134	8109	7747	7095	7084	7070	6755	6693	6690	6596
Port Everglades	8161	8136	7774	7122	7111	7097	6782	6720	6717	6623
Palm Beach	8207	8182	7820	7168	7157	7143	6828	6766	6763	6669
Jacksonville	8463	8438	8076	7424	7413	7399	7084	7022	7019	6925
Brunswick	8545	8520	8158	7506	7495	7481	7166	7104	7101	7007
Savannah	8649	8624	8262	7610	7599	7585	7270	7208	7205	7111
Charleston	8751	8726	8364	7712	7701	7687	7372	7310	7307	7213
Wilmington	8902	8877	8515	7863	7852	7838	7523	7461	7458	7364
Newport News	9262	9237	8875	8223	8212	8198	7883	7821	7818	7724
Baltimore	9432	9407	9045	8393	8382	8368	8053	7991	7988	7894
Chester	9509	9484	9122	8470	8459	8445	8130	8068	8065	7971
Philadelphia	9524	9499	9137	8485	8474	8460	8145	8083	8080	7986
Perth Amboy	9744	9719	9357	8705	8694	8680	8365	8303	8300	8206
Newark	9759	9734	9372	8720	8709	8695	8380	8318	8315	8221
New York City	9771	9746	9384	8732	8721	8707	8392	8330	8327	8233
Boston	10157	10132	9770	9118	9107	9093	8778	8716	8713	8619
Portland, ME	10257	10232	9870	9218	9207	9193	8878	8816	8813	8719
Detroit	12146	12121	11759	11107	11096	11082	10767	10705	10702	10608
Port Huron	12208	12183	11821	11169	11158	11144	10829	10767	10764	10670
Chicago	12779	12754	12392	11740	11729	11715	11400	11338	11335	11241

Continued on next page

	Corpus Christi, TX	Freeport, TX	Galveston, TX	Houston, TX	Port Arthur, TX	New Orleans, LA	Gulfport, MS	Mobile, AL	Panama City, FL	Tampa, FL	Miami, FL
Corpus Christi	0										
Freeport	160	0									
Galveston	244	84	0								
Houston	291	131	47	0							
Port Arthur	423	263	179	132	0						
New Orleans	864	704	620	573	441	0					
Gulfport	1135	975	891	844	712	271	0				
Mobile	1233	1073	989	942	810	369	98	0			
Panama City	1426	1266	1182	1135	1003	562	291	193	0		
Tampa	1691	1531	1447	1400	1268	827	556	458	265	0	
Miami	2134	1974	1890	1843	1711	1270	999	901	708	443	0
Port Everglades	2161	2001	1917	1870	1738	1297	1026	928	735	470	27
Palm Beach	2207	2047	1963	1916	1784	1343	1072	974	781	516	73
Jacksonville	2463	2303	2219	2172	2040	1599	1328	1230	1037	772	329
Brunswick	2545	2385	2301	2254	2122	1681	1410	1312	1119	854	411
Savannah	2649	2489	2405	2358	2226	1785	1514	1416	1223	958	515
Charleston	2751	2591	2507	2460	2328	1887	1616	1518	1325	1060	617
Wilmington	2902	2742	2658	2611	2479	2038	1767	1669	1476	1211	768
Newport News	3262	3102	3018	2971	2839	2398	2127	2029	1836	1571	1128
Baltimore	3432	3272	3188	3141	3009	2568	2297	2199	2006	1741	1298
Chester	3509	3349	3265	3218	3086	2645	2374	2276	2083	1818	1375
Philadelphia	3524	3364	3280	3233	3101	2660	2389	2291	2098	1833	1390
Perth Amboy	3744	3584	3500	3453	3321	2880	2609	2511	2318	2053	1610
Newark	3759	3599	3515	3468	3336	2895	2624	2526	2333	2068	1625
New York City	3771	3611	3527	3480	3348	2907	2636	2538	2345	2080	1637
Boston	4157	3997	3913	3866	3734	3293	3022	2924	2731	2466	2023
Portland, ME	4257	4097	4013	3966	3834	3393	3122	3024	2831	2566	2123
Detroit	6146	5986	5902	5855	5723	5282	5011	4913	4720	4455	4012
Port Huron	6208	6048	5964	5917	5785	5344	5073	4975	4782	4517	4074
Chicago	6779	6619	6535	6488	6356	5915	5644	5546	5353	5088	4645

Continued on next page

	Port Everglades, FL	Palm Beach, FL	Jacksonville, FL	Brunswick, GA	Savannah, GA	Charleston, SC	Wilmington, NC	Newport News, VA	Baltimore, MD	Chester, PA	Philadelphia, PA
Port Everglades	0										
Palm Beach	46	0									
Jacksonville	302	256	0								
Brunswick	384	338	82	0							
Savannah	488	442	186	104	0						
Charleston	590	544	288	206	102	0					
Wilmington	741	695	439	357	253	151	0				
Newport News	1101	1055	799	717	613	511	360	0			
Baltimore	1271	1225	969	887	783	681	530	170	0		
Chester	1348	1302	1046	964	860	758	607	247	77	0	
Philadelphia	1363	1317	1061	979	875	773	622	262	92	15	0
Perth Amboy	1583	1537	1281	1199	1095	993	842	482	312	235	220
Newark	1598	1552	1296	1214	1110	1008	857	497	327	250	235
New York City	1610	1564	1308	1226	1122	1020	869	509	339	262	247
Boston	1996	1950	1694	1612	1508	1406	1255	895	725	648	633
Portland, ME	2096	2050	1794	1712	1608	1506	1355	995	825	748	733
Detroit	3985	3939	3683	3601	3497	3395	3244	2884	2714	2637	2622
Port Huron	4047	4001	3745	3663	3559	3457	3306	2946	2776	2699	2684
Chicago	4618	4572	4316	4234	4130	4028	3877	3517	3347	3270	3255

	Perth Amboy, NJ	Newark, NJ	New York City, NY	Boston, MA	Portland, ME	Detroit, MI	Port Huron, MI	Chicago, IL
Perth Amboy	0							
Newark	15	0						
New York City	27	12	0					
Boston	413	398	386	0				
Portland, ME	513	498	486	100	0			
Detroit	2402	2387	2375	1989	1889	0		
Port Huron	2464	2449	2437	2051	1951	62	0	
Chicago	3035	3020	3008	2622	2522	633	571	0

Source: *Department of Commerce, NOAA & National Ocean Service*

TABLE 31. Aggregate Trade Disruptions - Various Spatial Weights

VARIABLES	(1) Export	(2) Import	(3) Export	(4) Import	(5) Export	(6) Import	(7) Export	(8) Import
SAR - ATE	0.281	-0.074	0.300	-0.075	0.298	-0.087	0.287	-0.075
	(0.257)	(0.134)	(0.260)	(0.134)	(0.258)	(0.134)	(0.256)	(0.134)
SEM - ATE	0.286	-0.074	0.286	-0.074	0.286	-0.073	0.285	-0.075
	(0.261)	(0.134)	(0.244)	(0.132)	(0.245)	(0.112)	(0.257)	(0.133)
SAC - ATE	0.284	-0.074	0.293	-0.075	0.292	-0.080	0.287	-0.075
	(0.259)	(0.134)	(0.252)	(0.133)	(0.251)	(0.122)	(0.258)	(0.133)
Observations	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No	No	No	No
Spatial-Weighting	1st Order	1st Order	2nd Order	2nd Order	4th Order	4th Order	Inv. Dist.	Inv. Dist.

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

TABLE 32. Regional Trade Disruptions - Various Spatial Weights

VARIABLES	(1) Export	(2) Import	(3) Export	(4) Import	(5) Export	(6) Import	(7) Export	(8) Import
SAR								
Gulf Coast	0.065	0.114	0.132	0.126	0.174	0.216	0.059	0.112
	(0.253)	(0.408)	(0.239)	(0.408)	(0.240)	(0.384)	(0.249)	(0.406)
Lower Atlantic	1.003	0.618	1.052	0.630	1.082	0.693	0.997	0.615
	(0.920)	(0.487)	(0.926)	(0.490)	(0.928)	(0.488)	(0.913)	(0.486)
SEM								
Gulf Coast	0.047	0.113	0.147	0.126	0.203	0.220	0.061	0.111
	(0.265)	(0.405)	(0.237)	(0.395)	(0.235)	(0.326)	(0.250)	(0.406)
Lower Atlantic	1.008	0.612	0.958	0.601	0.959	0.541	1.001	0.614
	(0.942)	(0.484)	(0.847)	(0.466)	(0.824)	(0.374)	(0.925)	(0.486)
SAC								
Gulf Coast	-0.116	0.109	-0.345	0.122	0.719*	0.213	0.062	0.113
	(0.772)	(0.447)	(1.487)	(0.431)	(0.397)	(0.410)	(0.250)	(0.407)
Lower Atlantic	1.278	0.672	1.557	0.654	1.271	0.704	1.003	0.616
	(1.777)	(0.619)	(2.118)	(0.563)	(1.105)	(0.603)	(0.926)	(0.487)
Observations	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	1st Order	1st Order	2nd Order	2nd Order	4th Order	4th Order	Inv. Dist.	Inv. Dist.

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

TABLE 33. Port-Specific Trade Disruptions - SAC

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
Seattle, WA	-0.121***	0.019***	0.047***	-0.062***	-0.131***	-0.053***
	(0.003)	(0.006)	(0.002)	(0.003)	(0.020)	(0.005)
Portland, OR	0.126***	0.120***	-0.237***	0.368***	-0.357***	0.230***
	(0.011)	(0.005)	(0.003)	(0.004)	(0.026)	(0.009)
Oakland, CA	0.052***	0.010***	0.091***	-0.015***	0.197***	0.028**
	(0.017)	(0.003)	(0.006)	(0.006)	(0.040)	(0.013)
Richmond, CA	0.016	0.287***	0.302***	-0.671***	0.803***	-0.168***
	(0.016)	(0.001)	(0.005)	(0.004)	(0.029)	(0.011)
San Francisco, CA	0.652***	-0.388***	-0.164***	-0.185***	-0.595***	0.210***

Continued on next page

Table 33 – *Continued*

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
	(0.024)	(0.008)	(0.006)	(0.005)	(0.041)	(0.016)
Port Hueneme, CA	-0.017***	-0.281***	0.944***	-1.047***	**1.357*** **	-0.677***
	(0.006)	(0.011)	(0.003)	(0.002)	(0.026)	(0.005)
Los Angeles, CA	-0.141***	-0.022***	0.181***	0.001	0.243***	0.084***
	(0.016)	(0.006)	(0.005)	(0.003)	(0.073)	(0.002)
Long Beach, CA	-0.132***	0.033***	0.239***	-0.015***	0.302***	-0.047***
	(0.016)	(0.000)	(0.004)	(0.002)	(0.065)	(0.004)
San Diego, CA	0.733***	0.527***	-0.435***	0.608***	-0.594***	0.324***
	(0.023)	(0.005)	(0.006)	(0.001)	(0.078)	(0.004)
Chicago, IL	0.131***	-0.370***	0.205***	-0.004	**-2.503*** **	0.360***
	(0.048)	(0.008)	(0.002)	(0.009)	(0.035)	(0.092)
Port Huron, MI	0.060	-0.268***	-0.285***	-0.090***	-0.108*	-0.025
	(0.043)	(0.003)	(0.003)	(0.006)	(0.057)	(0.060)
Detroit, MI	0.089**	0.210***	0.002	0.125***	-0.791***	0.237***
	(0.042)	(0.004)	(0.003)	(0.006)	(0.029)	(0.049)
Portland, ME	-0.336***	0.140***	-0.312***	**-1.462*** **	**-1.961*** **	**-4.011*** **
	(0.034)	(0.002)	(0.005)	(0.001)	(0.004)	(0.005)
Boston, MA	0.078	-0.140***	0.297***	0.092***	0.078***	0.238***
	(0.051)	(0.001)	(0.004)	(0.010)	(0.009)	(0.035)
New York, NY	0.093*	-0.049***	0.269***	-0.051***	0.323***	0.248***
	(0.050)	(0.001)	(0.006)	(0.009)	(0.010)	(0.033)
Newark, NJ	0.038	-0.045***	0.389***	-0.023**	0.393***	0.112***
	(0.051)	(0.004)	(0.007)	(0.009)	(0.022)	(0.033)
Perth Amboy, NJ	-0.387***	-0.547***	0.515***	**-1.468*** **	0.807***	1.004***
	(0.037)	(0.000)	(0.009)	(0.001)	(0.040)	(0.005)
Philadelphia, PA	0.152***	-0.083***	0.367***	0.162***	0.267***	0.207***
	(0.047)	(0.004)	(0.009)	(0.005)	(0.047)	(0.012)
Chester, PA	-0.103***	-0.140***	0.536***	0.042***	0.468***	0.182***
	(0.025)	(0.005)	(0.008)	(0.004)	(0.051)	(0.019)
Baltimore, MD	-0.081***	-0.051***	0.217***	0.065***	0.242***	0.218***
	(0.025)	(0.006)	(0.009)	(0.004)	(0.048)	(0.017)
Newport News, VA	0.014	0.013***	0.237***	0.051***	0.229***	0.107***
	(0.020)	(0.001)	(0.008)	(0.002)	(0.046)	(0.013)
Wilmington, NC	0.994***	-0.196***	0.324***	0.272***	0.867***	0.881***
	(0.055)	(0.000)	(0.006)	(0.002)	(0.040)	(0.010)
Charleston, SC	-0.036	-0.032***	0.101***	-0.005***	-0.047	0.030***
	(0.032)	(0.001)	(0.006)	(0.001)	(0.049)	(0.005)
Savannah, GA	-0.042	0.071***	0.348***	0.201***	0.599***	0.505***
	(0.032)	(0.001)	(0.005)	(0.003)	(0.041)	(0.014)
Brunswick, GA	-0.825***	-0.340***	-0.269***	-0.750***	0.312***	**-1.049*** **
	(0.016)	(0.005)	(0.008)	(0.001)	(0.046)	(0.003)
Jacksonville, FL	0.167***	0.104***	0.283***	0.114***	0.368***	0.504***
	(0.052)	(0.002)	(0.005)	(0.004)	(0.036)	(0.028)
Palm Beach, FL	0.065	-0.140***	0.310***	-0.423***	0.084*	-0.914***
	(0.053)	(0.008)	(0.006)	(0.002)	(0.044)	(0.003)
Port Everglades, FL	-0.406***	0.145***	0.433***	0.026**	0.486***	-0.046
	(0.098)	(0.029)	(0.038)	(0.012)	(0.138)	(0.039)

Continued on next page

Table 33 – *Continued*

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
Miami, FL	-0.611***	-0.037	0.083**	-0.148***	-0.048	-0.114*
	(0.119)	(0.041)	(0.041)	(0.016)	(0.153)	(0.063)
Corpus Christi, TX	-0.082***	-0.564***	-0.259***	**2.331*** **	**2.954*** **	**1.382*** **
	(0.010)	(0.011)	(0.003)	(0.001)	(0.032)	(0.006)
Houston, TX	0.177*	0.015	0.324***	0.139***	0.421***	0.194***
	(0.091)	(0.044)	(0.005)	(0.004)	(0.053)	(0.037)
Freeport, TX	0.080***	-0.134***	0.152***	-0.786***	0.017	-0.674***
	(0.026)	(0.009)	(0.007)	(0.004)	(0.062)	(0.016)
Galveston, TX	0.700***	0.017	-0.069***	0.250***	0.582***	0.441***
	(0.060)	(0.017)	(0.007)	(0.001)	(0.054)	(0.028)
Port Arthur, TX	-0.545***	0.162***	**1.736*** **	**-1.525*** **	0.217***	**-2.986*** **
	(0.074)	(0.033)	(0.003)	(0.005)	(0.038)	(0.005)
Tampa, FL	-0.702***	0.231***	0.480***	0.415***	0.437***	0.913***
	(0.094)	(0.016)	(0.037)	(0.012)	(0.136)	(0.038)
Panama City, FL	**7.625*** **	**2.102*** **	**10.578*** **	**5.230*** **	**10.202*** **	**5.036*** **
	(0.090)	(0.028)	(0.004)	(0.003)	(0.036)	(0.003)
Mobile, AL	-0.179***	0.522***	0.596***	0.422***	**1.308*** **	**1.077*** **
	(0.044)	(0.009)	(0.040)	(0.007)	(0.125)	(0.014)
New Orleans, LA	**-1.757*** **	**-1.908*** **	**0.041**	**-0.464*** **	**0.125**	**0.034**
	(0.088)	(0.019)	(0.041)	(0.010)	(0.144)	(0.025)
Gulfport, MS	**-1.729*** **	**-1.788*** **	**-0.566*** **	**-0.761*** **	**-0.815*** **	**-0.682*** **
	(0.073)	(0.020)	(0.045)	(0.012)	(0.152)	(0.038)
Observations	1,120	1,120	1,960	1,960	4,840	4,840
R-squared	0.000	0.014	0.000	0.012	0.000	0.064
Port FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-Weighting	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order	3rd Order
Convergence	yes	yes	yes	yes	yes	yes

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

TABLE 34. Port Characteristics Legend Key

	Entrance Restrictions	
Harbor Type	Tide	Other
0 - Coastal (Breakwater)		
1 - Coastal (Natural)	0 - No	0 - No
2 - Coastal (Tide Gates)	1- Yes	1- Yes
3 - Canal or Lake		
4 - River (Basin)		
5 - River (Natural)		
6 - River (Tide Gates)		

Source: 2015 WPI - *National Geospatial-Intelligence Agency*

TABLE 35. Influence of Port Characteristics on Treatment Effects - SAC

	(1)	(2)	(3)	(4)	(5)	(6)
	Short-Run		**Medium-Run**		**Long-Run**	
VARIABLES	Export	Import	Export	Import	Export	Import
HT (=1)	-0.682	-0.069	**-1.568****	-0.112	**-1.640****	-0.423
	(0.551)	(0.203)	(0.666)	(0.528)	(0.665)	(0.565)
HT (=2)	0.011	**-0.284****	-0.475*	0.244	**-3.389*****	0.289
	(0.213)	(0.103)	(0.278)	(0.405)	(0.360)	(0.421)
HT (=3)	**-2.481****	-0.257	-1.764	**-2.889*****	**-3.846*****	**-4.723*****
	(1.166)	(0.353)	(1.433)	(0.851)	(1.323)	(0.915)
HT (=4)	-0.449	-0.061	**-0.860***	-0.100	**-1.135****	-0.296
	(0.351)	(0.131)	(0.444)	(0.447)	(0.479)	(0.475)
HT (=5)	-0.394	-0.158	**-1.100****	-0.200	**-1.274****	0.026
	(0.396)	(0.151)	(0.470)	(0.479)	(0.491)	(0.493)
HT (=6)	-1.570	-0.351	**-2.882****	-1.056	**-3.311****	-1.369
	(1.056)	(0.322)	(1.298)	(0.788)	(1.205)	(0.848)
ER - Tide	**-0.630***	-0.005	-0.643	-0.298	**-0.721***	**-0.835***
	(0.350)	(0.124)	(0.396)	(0.341)	(0.401)	(0.450)
ER - Other	-1.026	-0.199	**-1.383***	-0.156	-0.692	0.160
	(0.660)	(0.206)	(0.785)	(0.456)	(0.726)	(0.641)
Inv. Dist.	985.466	274.106	**1,530.182****	**874.352****	**1,723.503****	**903.609****
	(584.907)	(173.251)	(714.277)	(375.725)	(644.449)	(394.423)
Observations	37	37	37	37	37	37
R-squared	0.508	0.403	0.618	0.509	0.656	0.540
Std. Errors	Robust	Robust	Robust	Robust	Robust	Robust

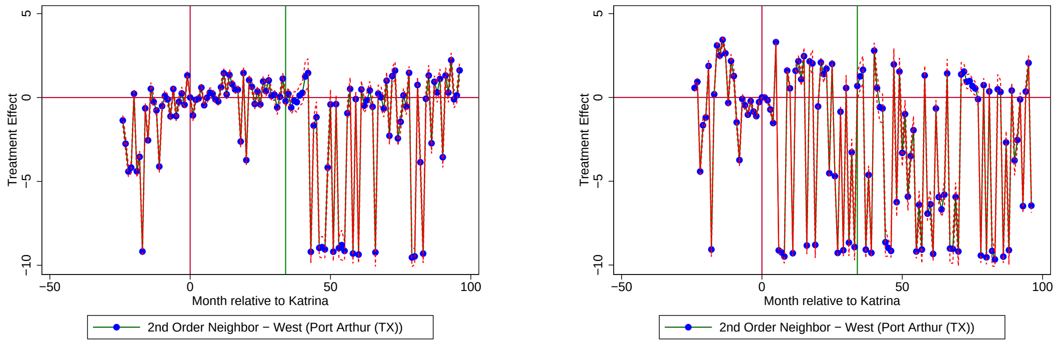
Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 36. Treatment Effect over Distance

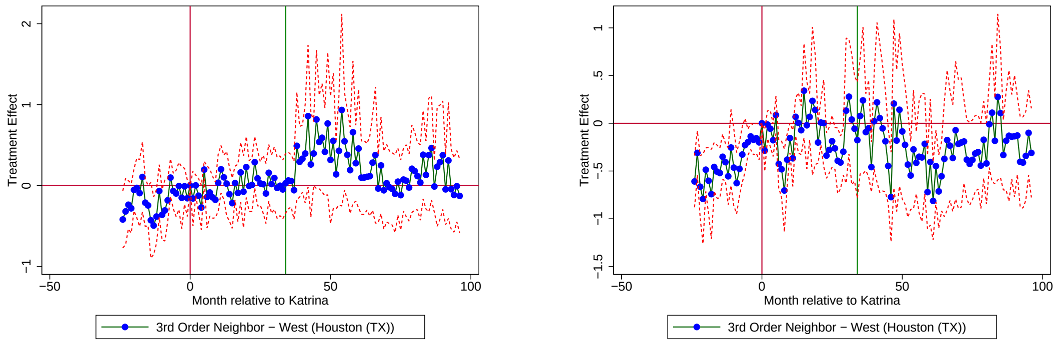
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	PPML		**SAR**		**SEM**		**SAC**	
VARIABLES	Export	Import	Export	Import	Export	Import	Export	Import
Core (LA, MS)	0.286***	-0.145***	0.366***	-0.128	0.174*	-0.200*	0.965**	-0.098
	(0.025)	(0.008)	(0.123)	(0.113)	(0.089)	(0.106)	(0.453)	(0.147)
Core*Inv. Dist.	-17.140***	-8.688***	-15.179***	-7.531***	-15.542***	-7.778***	-13.822***	-7.430***
	(0.000)	(0.000)	(0.274)	(0.066)	(0.763)	(0.575)	(3.865)	(0.415)
Periphery	-0.207	-0.153	-3.869***	-1.838***	-3.996***	-1.819***	-4.214***	-1.851***
(GA, FL, SC, TX)	(0.173)	(0.184)	(1.144)	(0.658)	(1.243)	(0.668)	(1.052)	(0.677)
Periphery*	189.283*	158.799	2,757.220***	1,359.084***	2,807.832***	1,343.031***	2,946.219***	1,367.465***
Inv. Dist.	(107.726)	(135.222)	(740.791)	(414.671)	(801.494)	(421.506)	(649.930)	(420.849)
Observations	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
R-squared	0.989	0.996	0.010	0.015	0.011	0.016	0.009	0.015
Port FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spatial-	None	None	3rd	3rd	3rd	3rd	3rd	3rd
Weighting			Order	Order	Order	Order	Order	Order
Convergence	yes	yes	yes	yes	yes	yes	yes	yes

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



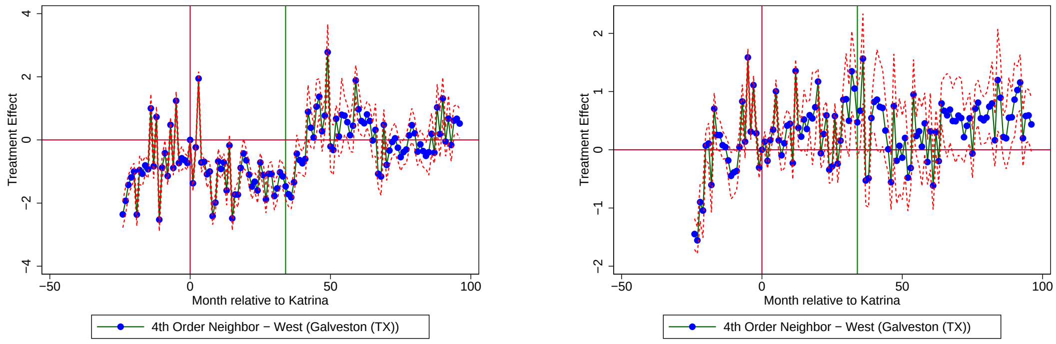
(a) Exports (b) Imports

FIGURE 18. Dynamic Treatment Effects - Port Arthur, TX



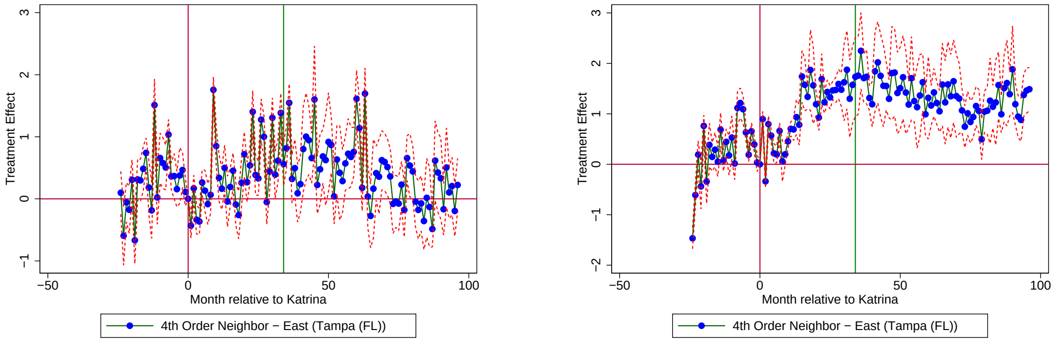
(a) Exports (b) Imports

FIGURE 19. Dynamic Treatment Effects - Houston, TX



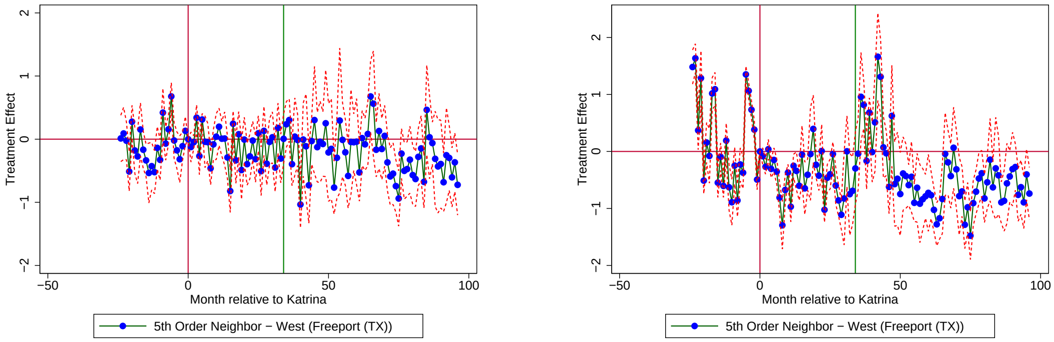
(a) Exports (b) Imports

FIGURE 20. Dynamic Treatment Effects - Galveston, TX



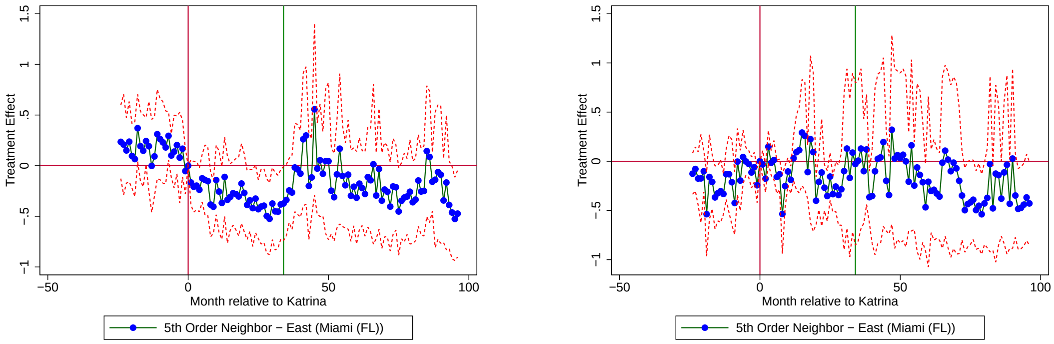
(a) Exports (b) Imports

FIGURE 21. Dynamic Treatment Effects - Tampa, FL



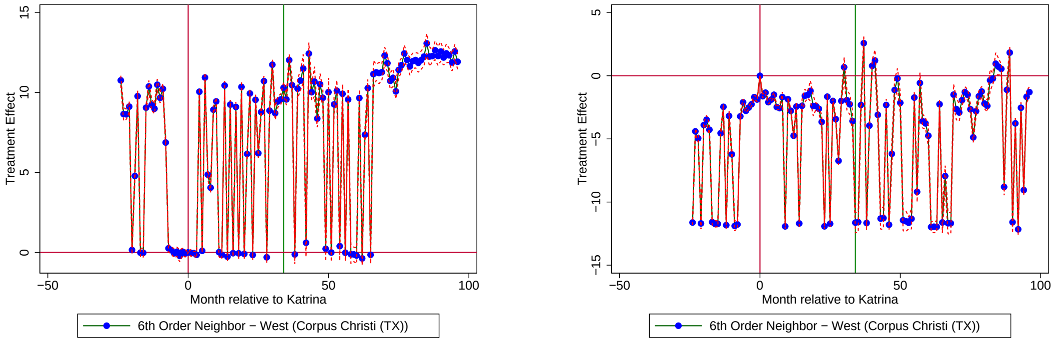
(a) Exports - Freeport, TX (b) Imports - Freeport, TX

FIGURE 22. Dynamic Treatment Effects - Freeport, TX



(a) Exports (b) Imports

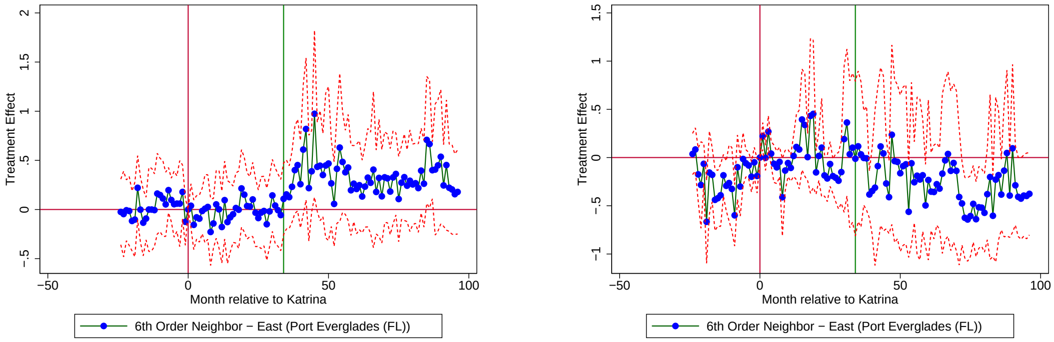
FIGURE 23. Dynamic Treatment Effects - Miami, FL



(a) Exports

(b) Imports

FIGURE 24. Dynamic Treatment Effects - Corpus Christi, TX



(a) Exports

(b) Imports

FIGURE 25. Dynamic Treatment Effects - Port Everglades, FL

REFERENCES CITED

Altay, N. and Ramirez, A. (2010). Impact of disasters on firms in different sectors: implications for supply chains. *Journal of Supply Chain Management*, 46(4):59–80.

Anderson, J. E. (2011). The gravity model. *Annual Review of Economics*, 3(1):133–160.

Anderson, J. E. and van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American Economic Review*, 93(1):170–192.

Anderson, J. E. and van Wincoop, E. (2004). Trade costs. *Journal of Economic Literature*, 42:691–751.

Anderton, C. H. and Carter, J. R. (2001). The impact of war on trade: An interrupted times-series study. *Journal of Peace Research*, 38(4):445–457.

Ando, M. and Kimura, F. (2012). How did the japanese exports respond to two crises in the international production networks? the global financial crisis and the great east japan earthquake. *Asian Economic Journal*, 26(3):261–287.

Andrade da Silva, J. and Cernat, L. (2012). Coping with loss: the impact of natural disasters on developing countries' trade flows. Technical report, Directorate General for Trade, European Commission.

Andriamananjara, S. (2004). Trade and international transport services: an analytical framework. *Journal of Economic Integration*, pages 604–625.

Armington, P. S. (1969). A theory of demand for products distinguished by place of production (une théorie de la demande de produits différenciés d'après leur origine)(una teoría de la demanda de productos distinguiéndolos según el lugar de producción). *Staff Papers-International Monetary Fund*, pages 159–178.

Auffret, P. (2003). High consumption volatility: The impact of natural disasters? *World Bank Policy Research Working Paper*, (2962).

Baier, S. L. and Bergstrand, J. H. (2001). The growth of world trade: tariffs, transport costs, and income similarity. *Journal of international Economics*, 53(1):1–27.

Baldwin, R. and Taglioni, D. (2006). Gravity for dummies and dummies for gravity equations. Technical report, National Bureau of Economic Research.

Basemann, R. and Daugherty, A. (1977). Complementarity in production and empty backhauls in transportation. In *Western Economics Association annual meeting.*

Baumol, W. J. and Vinod, H. D. (1970). An inventory theoretic model of freight transport demand. *Management science*, 16(7):413–421.

Behar, A. and Venables, A. J. (2011). 5 transport costs and international trade. *A Handbook of Transport Economics*, page 97.

Behrens, K., Gaigné, C., Ottaviano, G. I., and Thisse, J.-F. (2006). How density economies in international transportation link the internal geography of trading partners. *Journal of Urban Economics*, 60(2):248–263.

Behrens, K. and Picard, P. M. (2011). Transportation, freight rates, and economic geography. *Journal of International Economics*, 85(2):280–291.

Belasen, A. R. and Polachek, S. W. (2008). How hurricanes affect wages and employment in local labor markets. *The American Economic Review*, 98(2):49–53.

Bensassi, S., Martinez-Zarzoso, I., and Suárez, C. (2014). The effect of maritime transport costs on the extensive and intensive margins: Evidence from the europe–asia trade. *Maritime Economics & Logistics*, 16(3):276–297.

Bergstrand, J. H. (1985). The gravity equation in international trade: some microeconomic foundations and empirical evidence. *The review of economics and statistics*, pages 474–481.

Bergstrand, J. H. and Egger, P. (2011). Gravity equations and economic frictions in the world economy. *Palgrave Handbook of International Trade*, pages 532–570.

Bernard, A. B., Eaton, J., Jensen, J. B., and Kortum, S. (2003). Plants and productivity in international trade. *The American Economic Review*, 93(4):1268–1290.

Bernhofen, D. M., El-Sahli, Z., and Kneller, R. (2016). Estimating the effects of the container revolution on world trade. *Journal of International Economics*, 98:36–50.

Bertrand, M., Duflo, E., Mullainathan, S., et al. (2004). How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics*, 119(1):249–275.

Blonigen, B. A. and Wilson, W. W. (2008). Port efficiency and trade flows*. *Review of International Economics*, 16(1):21–36.

Blonigen, B. A. and Wilson, W. W. (2013). The growth and patterns of international trade. *Maritime Policy & Management*, 40(7):618–635.

Bosch, P., Coenen, P., Fridell, E., Åström, S., Palmer, T., and Holland, M. (2009). Cost benefit analysis to support the impact assessment accompanying the revision of directive 1999/32/ec on the sulphur content of certain liquid fuels. *AEA Report to European Commission, Didcot.*

Bougheas, S., Demetriades, P. O., and Morgenroth, E. L. (1999). Infrastructure, transport costs and trade. *Journal of International Economics*, 47(1):169–189.

Brander, J. A. and Spencer, B. J. (1984). Trade warfare: tariffs and cartels. *Journal of International Economics*, 16(3):227–242.

Burrus Jr, R. T., Dumas, C. F., Farrell, C. H., and Hall Jr, W. W. (2002). Impact of low-intensity hurricanes on regional economic activity. *Natural Hazards Review*, 3(3):118–125.

Carrere, C. (2006). Revisiting the effects of regional trade agreements on trade flows with proper specification of the gravity model. *European Economic Review*, 50(2):223–247.

Caruso, R. (2005). The impact of international economic sanctions on trade empirical evidence over the period 1960-2000. *Rivista Internazionale di Scienze Sociali*, pages 41–66.

Cavallo, E. A. and Noy, I. (2009). The economics of natural disasters: a survey.

Chang, S. E. (2000). Disasters and transport systems: loss, recovery and competition at the port of kobe after the 1995 earthquake. *Journal of transport geography*, 8(1):53–65.

Cheng, I.-H. and Wall, H. J. (2005). Controlling for heterogeneity in gravity models of trade and integration. *FEDERAL RESERVE BANK OF ST. LOUIS REVIEW*, 87(1):49–63.

Choi, I. (2001). Unit root tests for panel data. *Journal of international money and Finance*, 20(2):249–272.

Clark, X., Dollar, D., and Micco, A. (2004). Port efficiency, maritime transport costs, and bilateral trade. *Journal of development economics*, 75(2):417–450.

Clausing, K. A. (2001). Trade creation and trade diversion in the canada–united states free trade agreement. *Canadian Journal of Economics/Revue canadienne d'économique*, 34(3):677–696.

Cliff, A. D., O. K. (1969). The problem of spatial autocorrelation. *A. J. Scott, ed., Studies in Regional Science*, pages 25–55.

Combes, P.-P. and Lafourcade, M. (2005). Transport costs: measures, determinants, and regional policy implications for france. *Journal of Economic Geography*, 5(3):319–349.

CRED, T. C. f. R. o. E. o. D. (2015). The human cost of weather-related disasters 1995-2015.

Crespo Cuaresma, J., Hlouskova, J., and Obersteiner, M. (2008). Natural disasters as creative destruction? evidence from developing countries. *Economic Inquiry*, 46(2):214–226.

Cullinane, K. and Bergqvist, R. (2014). Emission control areas and their impact on maritime transport. *Transportation Research Part D: Transport and Environment*, 28:1–5.

Deardorff, A. (1998). Determinants of bilateral trade: Does gravity work in a neoclassical world? In *The Regionalization of the World Economy*, pages 7–32. University of Chicago Press.

Deardorff, A. V. (2014). Local comparative advantage: Trade costs and the pattern of trade. *International Journal of Economic Theory*, 10(1):9–35.

Demirel, E., Van Ommeren, J., and Rietveld, P. (2010). A matching model for the backhaul problem. *Transportation Research Part B: Methodological*, 44(4):549–561.

Dickey, D. A. and Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American statistical association*, 74(366a):427–431.

Dickey, D. A. and Said, S. E. (1981). Testing arima (p, 1, q) against arma (p+ 1, q). In *Proceedings of the Business and Economic Statistics Section, American Statistical Association*, volume 28, pages 318–22.

Dolfman, M. L., Wasser, S. F., and Bergman, B. (2007). Effects of hurricane katrina on the new orleans economy, the. *Monthly Lab. Rev.*, 130:3.

Donald, S. G. and Lang, K. (2007). Inference with difference-in-differences and other panel data. *The review of Economics and Statistics*, 89(2):221–233.

Dornbusch, R., Fischer, S., and Samuelson, P. A. (1977). Comparative advantage, trade, and payments in a ricardian model with a continuum of goods. *The American Economic Review*, pages 823–839.

Eaton, J. and Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, pages 1741–1779.

Egger, P. (2000). A note on the proper econometric specification of the gravity equation. *Economics Letters*, 66(1):25–31.

Egger, P. (2002). An econometric view on the estimation of gravity models and the calculation of trade potentials. *The World Economy*, 25(2):297–312.

Egger, P. and Gassebner, M. (2015). International terrorism as a trade impediment? *Oxford Economic Papers*, 67(1):42–62.

Egger, P. and Pfaffermayr, M. (2003). The proper panel econometric specification of the gravity equation: A three-way model with bilateral interaction effects. *Empirical Economics*, 28(3):571–580.

Egger, P. H. and Lassmann, A. (2012). The language effect in international trade: A meta-analysis. *Economics Letters*, 116(2):221–224.

Elliott, J. R. and Pais, J. (2006). Race, class, and hurricane katrina: Social differences in human responses to disaster. *Social Science Research*, 35(2):295–321.

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436(7051):686–688.

(EMSA), E. M. S. A. (2010). The 0.1% sulphur in fuel requirement as from 1 January 2015 in SECAs: An assessment of available impact studies and alternative means of compliance.

Endresen, Ø., Bakke, J., Sørgård, E., Berglen, T. F., and Holmvang, P. (2005). Improved modelling of ship so 2 emissionsa fuel-based approach. *Atmospheric Environment*, 39(20):3621–3628.

European Commission (2009). Commission recommendation of 21 december 2009 on the safe implementation of the use of low sulphur fuel by ships at berth in community ports.

European Commission (2015). Emissions from maritime transport; the directive 1999/32/EC.

Fan, L., Luo, M., and Wilson, W. W. (2014). Pricing joint products in liner shipping. *International Journal of Shipping and Transport Logistics 5*, 6(4):371–386.

Federal Maritime Commission et al. (2000). The ocean shipping reform act: An interim status report. *FMC, Washington, DC*.

Feenstra, R. C. (2002). Border effects and the gravity equation: consistent methods for estimation. *Scottish Journal of Political Economy*, 49:491–506.

Feenstra, R. C. and Romalis, J. (2014). International prices and endogenous quality*. *Quarterly Journal of Economics*, 129(2).

Felton, J. R. (1981). The impact of rate regulation upon icc-regulated truck back hauls. *Journal of Transport Economics and Policy*, pages 253–267.

Francois, J. F. and Wooton, I. (2001). Trade in international transport services: the role of competition. *Review of International Economics*, 9(2):249–261.

Frankel, J. and Rose, A. (2002). An estimate of the effect of common currencies on trade and income. *Quarterly Journal of economics*, pages 437–466.

Friedberg, L. (1998). Did unilateral divorce raise divorce rates? evidence from panel data. *The American Economic Review*, 88(3):608–627.

Friedt, F. L. (2016). The varying effectiveness of trade policy in the presence of endogenous transport costs. *mimeo*.

Friedt, F. L. and Wilson, W. W. (2015). Trade, transportation and trade imbalances: An empirical examination of international markets and backhauls. *Available at SSRN 2636983*.

Fusillo, M. (2013). The stability of market shares in liner shipping. *Review of Industrial Organization*, 42(1):85–106.

Gassebner, M., Keck, A., and Teh, R. (2010). Shaken, not stirred: the impact of disasters on international trade. *Review of International Economics*, 18(2):351–368.

Getis, A. (2009). Spatial weights matrices. *Geographical Analysis*, 41(4):404–410.

Glick, R. and Taylor, A. M. (2010). Collateral damage: Trade disruption and the economic impact of war. *The Review of Economics and Statistics*, 92(1):102–127.

Grenzeback, L. R., Lukman, A. T., and Systematics, C. (2008). *Case Study of the Transportation Sector's Response to and Recovery from Hurricane's Katrina and Rita*. Transportation Research Board.

Griffith, D. A. (1996). Some guidelines for specifying the geographic weights matrix contained in spatial statistical models. *Practical handbook of spatial statistics*, pages 65–82.

Guha-Sapir, D., Hoyois, P., and Below, R. (2015). Annual disaster statistical review 2014: The numbers and trends. *Centre for Research on the Epidemiology of Disasters (CRED)*, pages 1–33.

Hallegatte, S. (2008). An adaptive regional input-output model and its application to the assessment of the economic cost of katrina. *Risk analysis*, 28(3):779–799.

Hallstrom, D. G. and Smith, V. K. (2005). Market responses to hurricanes. *Journal of Environmental Economics and Management*, 50(3):541–561.

Hamilton, J. D. (1994). *Time series analysis*, volume 2. Princeton university press Princeton.

Harrigan, J. (1996). Openness to trade in manufactures in the oecd. *Journal of international economics*, 40(1):23–39.

Head, K. and Mayer, T. (2013). Gravity equations: Workhorse, toolkit, and cookbook. *Handbook of International Economics*, 4.

Head, K., Mayer, T., and Ries, J. (2010). The erosion of colonial trade linkages after independence. *Journal of International Economics*, 81(1):1–14.

Heaver, T. D. (1973). The structure of liner conference rates. *The Journal of Industrial Economics*, pages 257–265.

Heckscher, E. F. and Ohlin, B. G. (1991). *Heckscher-Ohlin trade theory*. The MIT Press.

Holtz-Eakin, D. (2005). *Macroeconomic and budgetary effects of Hurricanes Katrina and Rita*. HeinOnline.

Hornok, C., Koren, M., et al. (2011). Administrative barriers and the lumpiness of trade. *EFIGE WP*, (36).

Hummels, D. (2001). Toward a geography of trade costs.

Hummels, D. (2007). Transportation costs and international trade in the second era of globalization. *The Journal of Economic Perspectives*, pages 131–154.

Hummels, D., Lugovskyy, V., and Skiba, A. (2009). The trade reducing effects of market power in international shipping. *Journal of Development Economics*, 89(1):84–97.

Hummels, D. and Skiba, A. (2004). Shipping the good apples out? an empirical confirmation of the alchian-allen conjecture. *Journal of Political Economy*, 112(6):1384–1402.

Hummels, D. L. and Lugovskyy, V. (2006). Are matched partner trade statistics a usable measure of transportation costs? *Review of International Economics*, 14(1):69–86.

Ishikawa, J. and Tarui, N. (2015). Backfiring with backhaul problems.

Ivanov, N. C. (2010). The EU directive on low sulphur fuel (2005/33/EC): A legal and insurance industry perspective. *Assuranceforeningen SKULD*.

Jacks, D. S., Meissner, C. M., and Novy, D. (2008). Trade costs, 1870-2000. *The American Economic Review*, 98(2):529–534.

Jonkeren, O., Demirel, E., van Ommeren, J., and Rietveld, P. (2011). Endogenous transport prices and trade imbalances. *Journal of Economic Geography*, 11(3):509–527.

Jordan, W. C. (1987). Truck backhauling on networks with many terminals. *Transportation Research Part B: Methodological*, 21(3):183–193.

Kahn, M. E. (2005). The death toll from natural disasters: the role of income, geography, and institutions. *Review of economics and statistics*, 87(2):271–284.

Kao, C. and Chiang, M.-H. (1999). On the estimation and inference of a cointegrated regression in panel data. *Available at SSRN 1807931*.

Kleinert, J. and Spies, J. (2011). Endogenous transport costs in international trade. Technical report, IAW-Diskussionspapiere.

Korinek, J. (2011). Clarifying trade costs in maritime transport. *Working Party of the Trade Committee*.

Krugman, P. (1980). Scale economies, product differentiation, and the pattern of trade. *The American Economic Review*, 70(5):950–959.

Krugman, P. R. (1979). Increasing returns, monopolistic competition, and international trade. *Journal of international Economics*, 9(4):469–479.

Kunkel, K. E., Pielke Jr, R. A., and Changnon, S. A. (1999). Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: A review. *Bulletin of the American Meteorological Society*, 80(6):1077.

LeSage, J. P. and Pace, R. K. (2009). *Introduction to Spatial Econometrics (Statistics, textbooks and monographs)*. CRC Press.

Levin, A., Lin, C.-F., and Chu, C.-S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of econometrics*, 108(1):1–24.

Levinson, M. (2010). *The box: how the shipping container made the world smaller and the world economy bigger*. Princeton University Press.

Li, Q. and Sacko, D. H. (2002). The (ir) relevance of militarized interstate disputes for international trade. *International Studies Quarterly*, 46(1):11–43.

Limao, N. and Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. *The World Bank Economic Review*, 15(3):451–479.

Lin, H., Kuo, Y., Shaw, D., Chang, M., and Kao, T. (2012). Regional economic impact analysis of earthquakes in northern taiwan and its implications for disaster reduction policies. *Natural hazards*, 61(2):603–620.

Lipsey, R. E. and Weiss, M. Y. (1974). The structure of ocean transport charges. In *Explorations in Economic Research, Volume 1, Number 1*, pages 162–193. NBER.

Luo, Z. (2011). Transportation costs and trade imbalance: Theory and evidence.

Martincus, C. V. and Blyde, J. (2013). Shaky roads and trembling exports: Assessing the trade effects of domestic infrastructure using a natural experiment. *Journal of International Economics*, 90(1):148–161.

Martínez-Zarzoso, I., García-Menéndez, L., and Suárez-Burguet, C. (2003). Impact of transport costs on international trade: the case of spanish ceramic exports. *Maritime Economics & Logistics*, 5(2):179–198.

Martinez-Zarzoso, I. and Nowak-Lehmann, F. D. (2007). Is distance a good proxy for transport costs? the case of competing transport modes. *The Journal of International Trade & Economic Development*, 16(3):411–434.

Martínez-Zarzoso, I., Pérez-García, E. M., and Suárez-Burguet, C. (2008). Do transport costs have a differential effect on trade at the sectoral level? *Applied Economics*, 40(24):3145–3157.

Martínez-Zarzoso, I. and Suárez-Burguet, C. (2005). Transport costs and trade: empirical evidence for latin american imports from the european union. *Journal of International Trade & Economic Development*, 14(3):353–371.

Masozera, M., Bailey, M., and Kerchner, C. (2007). Distribution of impacts of natural disasters across income groups: A case study of new orleans. *Ecological Economics*, 63(2):299–306.

McCallum, J. (1995). National borders matter: Canada-us regional trade patterns. *The American Economic Review*, pages 615–623.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*, 71(6):1695–1725.

Meng, Y., Yang, S., Shi, P., and Jeager, C. (2015). The asymmetric impact of natural disasters on china's bilateral trade. *Natural Hazards and Earth System Science*, 15(10):2273–2281.

Mora, R. and Reggio, I. (2012). Treatment effect identification using alternative parallel assumptions.

Nicholson, H. W. (1958). Motor carrier costs and minimum rate regulation. *The Quarterly Journal of Economics*, pages 139–152.

Notteboom, T., Delhaye, E., and Vanherle, K. (2010). Analysis of the consequences of low sulphur fuel requirements. *ITMMA–Universiteit Antwerpen Transport&Mobility*.

Noy, I. (2009). The macroeconomic consequences of disasters. *Journal of Development economics*, 88(2):221–231.

Noy, I. and Vu, T. B. (2010). The economics of natural disasters in a developing country: The case of vietnam. *Journal of Asian Economics*, 21(4):345–354.

Obstfeld, M. and Rogoff, K. (2001). The six major puzzles in international macroeconomics: is there a common cause? In *NBER Macroeconomics Annual 2000, Volume 15*, pages 339–412. MIT press.

Oh, C. H. and Reuveny, R. (2010). Climatic natural disasters, political risk, and international trade. *Global Environmental Change*, 20(2):243–254.

Ord, K. (1975). Estimation methods for models of spatial interaction. *Journal of the American Statistical Association*, 70(349):120–126.

Parsons, C. R. (2014). Disasters and trade: did hurricane katrina affect us imports? *International Economics and Economic Policy*, pages 1–18.

Pedroni, P. (2000). Fully modified ols for heterogeneous cointegrated panels.

Pedroni, P. (2001). Purchasing power parity tests in cointegrated panels. *Review of Economics and Statistics*, 83(4):727–731.

Pedroni, P. (2004). Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the ppp hypothesis. *Econometric theory*, 20(03):597–625.

Pedroni, P. et al. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and statistics*, 61(s 1):653–670.

Pelli, M. and Tschopp, J. (2013). The creative destruction of hurricanes. Technical report, Working Paper.

Pesaran, M. H., Shin, Y., and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, 16(3):289–326.

Phillips, P. C. and Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2):335–346.

Pielke Jr, R. A., Gratz, J., Landsea, C. W., Collins, D., Saunders, M. A., and Musulin, R. (2008). Normalized hurricane damage in the united states: 1900–2005. *Natural Hazards Review*, 9(1):29–42.

P&O Ferrymasters. New rules on maritime fuel: a short guide to the impact on you.

Port Finance International (2013). Worlds largest containership sets sail from busan. Last accessed: 09/08/2015.

Raschky, P. A. (2008). Institutions and the losses from natural disasters. *Natural Hazards and Earth System Science*, 8(4):627–634.

Rasmussen, M. T. N. (2004). *Macroeconomic implications of natural disasters in the Caribbean.* Number 4-224. International Monetary Fund.

Rietveld, P. and Roson, R. (2002). Direction dependent prices in public transport: A good idea? the back haul pricing problem for a monopolistic public transport firm. *Transportation*, 29(4):397–417.

Rodrigue, J.-P., Comtois, C., and Slack, B. (2013). *The geography of transport systems*. Routledge.

Rose, A. (2007). Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. *Environmental Hazards*, 7(4):383–398.

Rose, A., Benavides, J., Chang, S. E., Szczesniak, P., and Lim, D. (1997). The regional economic impact of an earthquake: Direct and indirect effects of electricity lifeline disruptions. *Journal of Regional Science*, 37(3):437–458.

Rose, A. and Wei, D. (2013). Estimating the economic consequences of a port shutdown: the special role of resilience. *Economic Systems Research*, 25(2):212–232.

Rua, G. (2012). Fixed costs, network effects and the international diffusion of containerization. *Unpublished, October*.

Samuelson, P. A. (1952). Spatial price equilibrium and linear programming. *The American economic review*, pages 283–303.

Samuelson, P. A. (1954). The transfer problem and transport costs, ii: Analysis of effects of trade impediments. *The Economic Journal*, pages 264–289.

Santos Silva, J. and Tenreyro, S. (2006). The log of gravity. *The Review of Economics and statistics*, 88(4):641–658.

Schrooten, L., De Vlieger, I., Panis, L. I., Styns, K., and Torfs, R. (2008). Inventory and forecasting of maritime emissions in the belgian sea territory, an activity-based emission model. *Atmospheric Environment*, 42(4):667–676.

Sjostrom, W. (1992). Price discrimination by shipping conferences. *Logistics and Transportation Review*, 28(2):207.

Skidmore, M. and Toya, H. (2002). Do natural disasters promote long-run growth? *Economic Inquiry*, 40(4):664–687.

Smith, A. (1776). An inquiry into the nature and causes ofthe wealth ofnations. *London: George Routledge and Sons*.

Strobl, E. (2011). The economic growth impact of hurricanes: evidence from us coastal counties. *Review of Economics and Statistics*, 93(2):575–589.

Strobl, E. (2012). The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the central american and caribbean regions. *Journal of Development economics*, 97(1):130–141.

Strömberg, D. (2007). Natural disasters, economic development, and humanitarian aid. *The Journal of Economic Perspectives*, 21(3):199–222.

Takahashi, T. (2011). Directional imbalance in transport prices and economic geography. *Journal of urban Economics*, 69(1):92–102.

Talley, W. K. and Pope, J. A. (1985). Determinants of liner conference rates under containerization. *International Journal of Transport Economics/Rivista internazionale di economia dei trasporti*, pages 145–155.

Tanaka, K. and Tsubota, K. (2014). Directional imbalance of freight rates: evidence from japanese inter-prefectural data.

Thursby, J. G. and Thursby, M. C. (1987). Bilateral trade flows, the linder hypothesis, and exchange risk. *the Review of Economics and Statistics*, pages 488–495.

Tinbergen, J. (1962). Shaping the world economy; suggestions for an international economic policy. *Books (Jan Tinbergen)*.

Toya, H. and Skidmore, M. (2007). Economic development and the impacts of natural disasters. *Economics Letters*, 94(1):20–25.

Transportation Research Board (2006). Tr news september-october 2006: The intermodal container era: History, security, and trends. page 246.

UNCTAD, Secretariat (1979-2014). *Review of Maritime Transport 2014*. United Nations Publications.

Vigdor, J. (2008). The economic aftermath of hurricane katrina. *The Journal of Economic Perspectives*, 22(4):135–154.

Wallace, R. (n.d.). Definitions of eia distillate categories and fuels contained in the distillate grouping. *Department of Energy*.

Wilmsmeier, G., Hoffmann, J., and Sanchez, R. J. (2006). The impact of port characteristics on international maritime transport costs. *Research in Transportation Economics*, 16:117–140.

Wilson, W. W. (1987). Transport markets and firm behavior: the backhaul problem. In *Journal of the Transportation Research Forum*, volume 28.

Wilson, W. W. (1994). Market choice, entry regulation, and joint production: Market access and market service in motor carrier markets. *Review of Industrial Organization*, 9(6):791–812.

Wilson, W. W. and Beilock, R. (1994). Market access in regulated and unregulated markets: The continuing cost of interstate motor carrier regulation. *Journal of Regulatory Economics*, 6(4):363–379.

Wolfers, J. (2006). Did unilateral divorce laws raise divorce rates? a reconciliation and new results. *American Economic Review*, 96(5):1802–1820.

Xiao, Y. and Nilawar, U. (2013). Winners and losers: analysing post-disaster spatial economic demand shift. *Disasters*, 37(4):646–668.

Yang, D. (2008). Coping with disaster: The impact of hurricanes on international financial flows, 1970-2002. *The BE Journal of Economic Analysis & Policy*, 8(1).