DISTANCE FRICTION AND SPATIAL INTERACTION DYNAMICS OF INTERNATIONAL FREIGHT TRANSPORTATION

by

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ABSTRACT

PAUL H. JUNG. Distance friction and spatial interaction dynamics of international freight transportation. (Under the direction of DR. JEAN-CLAUDE THILL)

The modern economy runs with heavy reliance on the free flow of goods across the international logistic and supply chain. Advances in international freight transportation systems supported by intermodal integration, freight containerization, hub-and-spoke shipping system, and supply chain security, has reduced the distance friction of flow of goods and drastically lowered physical barriers of commercial activities. However, it is little known yet how spatial interactions of trade and shipping take place under the complex logistic chain process and what spatial phenomena ensue from such processes. In this dissertation, I study the nature of spatial interaction phenomena in the context of the contemporary state of the international transportation system. First, I study how the spatial structure of the port system is formed with intermodal integration of the modern international logistic system across land and water. Second, I explore how the hub-and-spoke system in the international transportation network contributes to the global shrinkage of space. Third, I investigate the effect of domestic armed conflicts developed by political instability on freight mobility and ensuing differential openness of regions to the global market. Results of the three pieces of research are as follows. First, the spatial structure of the port system is found to comprise interdependent collections of hinterlands, feeder and hub ports, and forelands along a logistical continuum, which mirror the functional division of logistic processes across space. Second, the hub-and-spoke shipping system reduces the distance friction of shipping flows and is the main driver of global shrinkage of space in terms of long-distance trade. Third, freight mobility is found to be greatly compromised by the lack of logistic chain security stemming from prevailing armed violence along inland transportation corridors. The findings confirm that intermodal logistic integration, hub-and-spoke distribution system and supply chain security are important key components of the modern international transportation system that determine global-scale spatial organization, shipping flow and freight mobility.

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INTRODUCTION

The international freight transportation system is the backbone of the contemporary globalized economy. It is now beyond one's imagination that the economy would run without the free flow of goods across the international logistic and supply chain. Across countries and industries, local businesses survive by relying on a larger system of the international logistic and supply chains that entails intertwined economic connections with distant foreign markets and suppliers (Dicken 2007). Supported by intermodal integration, freight containerization, hub-and-spoke shipping system, and supply chain security, the advanced efficiency in the international logistic system of the 20th Century has tremendously reduced distance friction in transporting freights, exponentiated the amount of the long-distance commerce, spurred cross-border market integration and resulted in the shrinkage of the space (Hesse and Rodrigue 2004, Knowles 2006). A simple statistic confirms this; while the physical length of international trade routes has remained constant, the worldwide gross volume of the container traffic has more than tripled from to 225 million to 793 million twenty-foot equivalent units (TEUs) between 2000 and 2018 (UNCTAD 2020).

How has the geographical space changed in response to the global-scale economic integration induced by international logistic and supply chain systems? Geographers have discussed how long-distance trade flows take place in the context of the modern international logistic system. From different angles, multiple aspects of the global-scale spatial economic interactions have been studied to better understand the geographical fundamentals of the modern globalized economy at local and global scales. For instance, the literature of transport geography has reported that the freight containerization and intermodal integration across land and water have resulted in increasing global-scale connectivity between distant places and transformed the way how local- and global-scale economic spaces are organized (e.g., Janelle 1969, Notteboom and Rodrigue 2005, Knowles 2006, Rodrigue and Notteboom 2010, Hesse 2013). A notion of accelerating long-distance commerce led to dauntless defiance to Tobler's (1970) first law of geography and went as far as to proclaim the "death of distance" (e.g., Cairncross 1997, Glaeser and Kohlhase 2004, Knowles 2006, Hummels 2007). The development of hub-and-spoke shipping systems has been viewed as a main driver that fundamentally changes the way of global-scale spatial economic interactions, like airline and maritime transportation, and offsets the distance friction of long-distance commerce (O'Kelly 1998, O'Kelly and Bryan 1998, Knowles 2006, Hummels 2007). Some research has studied how logistic and supply chain security guarantees the free flow of goods and the efficient operation of the logistic system. Research has also discussed how to achieve a higher level of global-scale freight mobility and how to improve the openness of local economies to the global market (e.g., Anderson and Marcouiller 2002, Blomberg and Hess 2006, Bendall 2010, Sequeira and Djankov 2014, Besley *et al.* 2015).

Even though different ideas on the geographical meaning of global economic integration have been suggested, a substantial part of the question remains unanswered. A big hurdle to the research has been the lack of micro-level trade data that trace detailed movement trajectories of goods across land and sea. Inevitably, previous empirical studies have focused on bilateral country-to-country trade flows, rather than location-to-location.

Analysis without the disaggregated trade shipping data could not address the complexity of multiple logistic processes that take place as multi-lateral shipping flows, such as transshipping behaviors, hub-and-spoke distribution and intermodal integration across land and sea, which are key features of modern international freight transportation. In the present literature, there is no empirical validation that addresses such features.

My dissertation reexamines the natures of spatial interaction phenomena in the context of the contemporary state of the international transportation system. I aim to characterize how spatial interactions of trade and shipping take place under the complex logistic chain process and what spatial phenomena ensue from such processes. For this aim, I focus on three major fundamental elements of economic geography: 1) Spatial organization, 2) distance friction and 3) freight mobility. In consideration of the complexity of intermodal logistic chain processes, how can spatial organization, spatial interaction and distance friction effects be traced in the movement of international trade shipment? Specifically, how can spatial economic structures be described by addressing intermodal integration across land and sea around ports? Is the advance in the international logistic system followed by a decrease in the power of distance in limiting economic interaction over space? In what situation can local economies achieve higher freight mobility and accessibility to the global market?

As summarized in Figure 1, I approach the raised questions above by investigating three major features of the contemporary international transportation system: 1) The sea-land intermodal integration, 2) hub-and-spoke distribution system and 3) logistics and supply chain security. First, I examine international shipping flows across land and sea to study how the spatial structure of the port system is shaped through the logistic integration

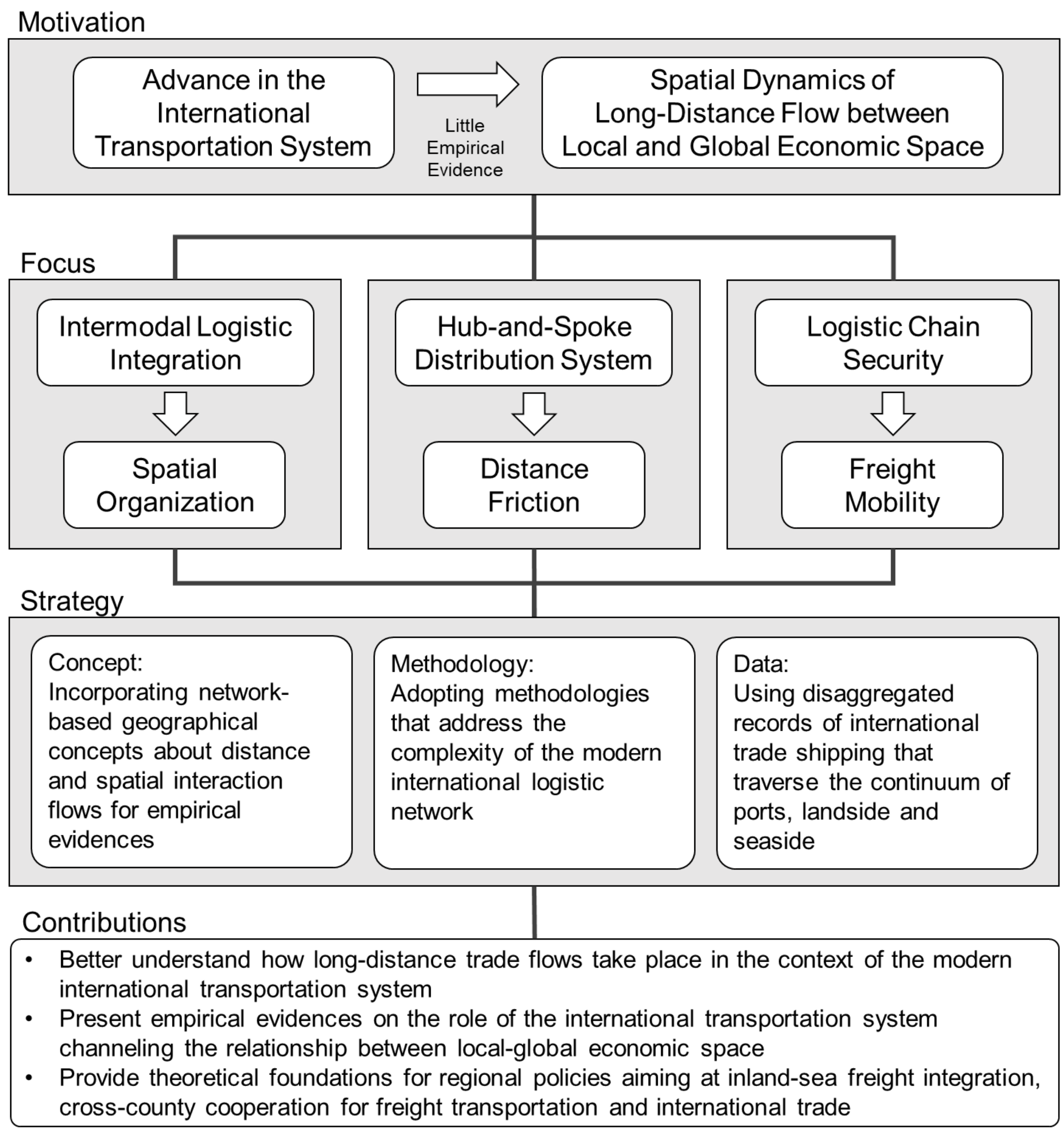

Figure 1 Roadmap of dissertation

among ports, forelands and hinterlands. Second, the hub-and-spoke distribution system is investigated to see how it creates economies of scale and reduces distance friction in transporting international trade cargoes across trade routes. Third, I examine port choice behaviors of export shipping in Colombia to reveal how freight mobility and global market access are degraded by expanded distance friction in response to the risk of insecurity along trade routes, like exposure to crime and domestic armed conflicts.

I set up strategies commonly applied to the three topics. Unlike previous studies using aggregated country-to-country freight flow data, I use disaggregated freight shipping records, the Port Import Export Record Services (PIERS), to track detailed logistic trajectories. Since the PIERS database provides detailed records of bills of lading bound for U.S. ports, important points along shipping trajectories can be tracked, such as shippers' address, traversed ports and the U.S. ports of entry of each shipment, I can trace the logistic process under which each cargo is shipped over the trade route. This allows addressing shipments' complex logistic chain processes across land and water, like intermodal shipment, transshipment, and hub-and-spoke distribution, which could not be easily addressed in previous studies. Also, different concepts of distance friction and spatial interactions are employed to explain how trade shipping flows take place differently across the stages of the logistic chain process. I adopt theories and methodologies from network science, functional regionalization, and discrete choice modeling to examine embedded global spatial structures and spatial interaction patterns in the complex trade shipping data.

In chapter 1, I study how the spatial structure of the port system is formed with intermodal integration of the modern international logistic system across land and water. Previous port-driven regional development models have focused only on landside port-hinterland spatial structures in the ports' vicinity, not seaside inter-port connections together. However, I acknowledge that the sea-land intermodal integration and transshipment are core characteristics of the modern international logistic system, and argue that the spatial structure of the port system should consider both flows to and from ports together when tracing spatial structures of hinterlands and forelands. Incorporating the network-based analytical model of the nonparametric weighted stochastic blockmodel, I examine how global-scale structures of hinterlands and forelands emerge with integrated landside-seaside freight flow dynamics. I investigate the network block structures of cargo shipping routes and detect different network blocks of hinterlands and forelands structures in Europe based on transportation flow patterns across land and sea. The spatial representation of the hinterland and foreland structures reveals the functional division of logistic processes across space, interdependent relationships between hinterlands and forelands and the extent to which the hinterland- and foreland-side transportation systems work.

In chapter 2, I explore how the hub-and-spoke system in the international transportation network contributes to the global shrinkage of space. The friction in long-distance trade routes varies by the location of shippers and nodal characteristics of traversed ports, and quality of scale economies driven by the hub-and-spoke distribution system along the trajectory of the logistic process. Despite the greater length of shipping routes, large streams of trade shipping are now processed through transshipment routes via hub ports, rather than direct routes with a shorter distance, to better take advantage of hub-and-spoke shipping economies. In order to confirm the shrinkage of space brought about by the hub-and-spoke shipping economies, I examine disaggregated cross-Atlantic cargo shipping trajectory data from Europe to the U.S. recorded both on landside and seaside. A discrete choice model was adopted to examine how the hub-and-spoke configuration affects routing behaviors of shipments and how hub-and-spoke shipping economies arise. The results present that the hub-and-spoke shipping economies arise with scales of ports' landside and maritime operation and shipping line diversity and that they offset distance friction that occurs along landside and maritime shipping voyages. The hub-and-spoke system is confirmed as a main driver of global shrinkage of space in terms of long-distance commercial activities.

In chapter 3, I investigate the effect of domestic armed conflicts developed by political instability on the freight mobility and ensuing differential openness of regions to the global market. Colombia's transportation system has been found to be impeded by a lack of inland transport infrastructure and institutions and fragmented political environments. U.S.-bound export shipping records corroborate that a significant portion of the export freight shipping from inland regions is forwarded to Atlantic ports over Pacific ports despite greatly extended inland shipping distances. I hypothesize that export freight shipping is re-routed to avoid exposures to the domestic armed conflicts and trade impedance increases as a result. I examine the trajectories of freight shipping from Colombian regions and spatial patterns of violent armed conflict data to determine how detrimental unstable geopolitical environments are to the shipping mobility and market openness. The discrete choice model of the port pairs presents that shipping flows are greatly curbed by the extended re-routing due to domestic armed conflicts and inland regions have limited access to the global market. The results highlight that political stability needs to be a priority for improved freight mobility and export-oriented transportation development policies.

The rest of the dissertation is structured as follows. Chapter 1 studies the spatial structure of the port system in Europe addressing sea-land intermodal logistic integration. Chapter 2 discusses the reduction in distance friction ensuing from the hub-and-spoke distribution system and provides evidence of the global-scale distance convergence. Chapter 3 presents a case study of Colombia that examines port choice patterns of the export freight shipping with relation to spatial patterns of the domestic armed conflicts as a disruption factor to the free flow of the freight shipping. The last chapter concludes and discusses limitations and implications for future research.

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CHAPTER 1: SEA-LAND INTERDEPENDENCE AND DELIMITATION OF PORT FORELAND-HINTERLAND STRUCTURES IN THE INTERNATIONAL TRANSPORTATION SYSTEM

1.1. Introduction

As logistic and supply chains have expanded to multiple points across countries, ports are now perceived as more critical elements in mediating local economic activities to the global market. In the literature, their unique function in the transportation system is well recognized as central places of shipping activities that drive urban agglomeration and regional economic growth mainly in their vicinity (Ducruet 2010). This notion remains influential today, and many researchers and policymakers are paying attention to how ports can drive economic growth in their surrounding urban region (Hall and Jacobs 2012). One classical approach is to examine port-hinterland relationships based on flow patterns on the land side and to trace how urban regions are structured with regard to ports and how they interface with nearby territories.

However, this approach may fall short of capturing the spatial dynamics of the modern port system. As the international freight shipping technology has evolved tremendously, transportation flows to and from ports have increased in complexity over time. Indeed, advances in the international logistic system, such as cargo containerization, intermodalism, and inland freight distribution centers, have fundamentally transformed the way ports and hinterlands interact spatially. Inland distribution, feeder and trunk line shipping and transshipping at intermediate hub ports are some of the multiple logistical processes that move international cargo and functionally integrates places in the economic space (Hesse and Rodrigue 2004, Woxenius 2012). Intermodal logistic integration has boosted the importance of hinterland-side transportation facilities placed beyond ports' direct vicinity. Also, foreland-side intermediate hub ports have taken on more critical roles in supporting multiple logistic chains across land and water (Rodrigue and Notteboom 2010). Thus, a port now operates not only as a central place to the surrounding urban region, but as one of multiple nodal points along the entire freight shipping corridor in support of integrated logistics and shipping.

The complexity of the modern port system calls for closer examination of both landside and seaside freight shipping flows as whole and of unfragmented flows across land and sea. It is already a few decades ago that a similar notion was first proposed in the literature as hinterland-foreland continuum (Robinson 1970) and port triptych (Vigarié 1979, Charlier 1992). Both concepts suggested that hinterland and foreland structures can be more meaningful when landward and seaward segments of the freight shipping flows are understood together. However, scan attention has been paid to how to corroborate such structures and empirical validation supporting this concept is rather sparse today. Constrained by the lack of data tracking freight shipping trajectories both on land and on sea, the research designs of recent empirical studies have only analyzed one of either the hinterland or foreland sides and paid lip service to the critical role of ports in interfacing the two sides. In addition, the development of new analytical tools has not been followed by substantive findings on spatial structures that emerge from the contemporary state of the logistic integration across land and sea.

The purpose of this paper is to study if and how the contemporary state of the logistic integration across land and sea shapes spatial structures of the port system. I revisit the concept of hinterland-foreland continuum and port triptych and the issue of spatial organization at the global scale. Based on the observation of the entire freight shipping flow trajectories spanning land and water, I examine how structures of hinterlands and forelands at the global scale emerge with landside-seaside flow dynamics concomitantly in the context of the modern port system. By doing so, I address the following questions: First, do hinterlands and forelands exist interdependently? If so, how can I define and delimit hinterlands and forelands based on their interdependent relationships with each other? What are the characteristics of interdependent relationships between hinterlands and forelands? Second, how are hinterland distributions spatially represented? What is the spatial extent of inland urban regions that are served by a port system? Third, how are functional relationships made between ports via transshipment? If ports do not only compete but also complement each other, does a functional division between hubs and feeders exist in the inter-port network?

To address these questions, I employ a network-based classification model, the nonparametric weighted stochastic block model (npWSBM). The npWSBM classifies network nodes into groups (or blocks) by similar connectivity patterns and structural equivalences from multi-adic connections. It is especially useful to characterize block-to-block relational structures from complex network data to simplify and quantify the whole network structure. I apply the npWSBM to Europe-U.S. containerized cargo shipping data that track trajectories from sources, ports, and finally to the U.S. piers. Since Europe has contestable markets of freight shipping and inter-port transshipment occurs frequently, the network-based views are useful to comprehend the spatial structure of economic territories that emerge from the logistic integration across land and sea. The model can comprehensively trace features that emerge from dyadic, triadic and even multi-adic interdependent structures across hinterlands and forelands. Cartographic representation of the network node blocks identified by npWSBM reveal the spatial structures embedded in the economic relations evidenced by freight shipping flows.

In the next section, I present the relevant background on the spatial structures of port systems and on the functional regionalization research to find their theoretical connections. Then the npWSBM is introduced as the method to empirically trace a network structure of the international freight shipping system. I also provide a general description of the data on U.S.-bound containerized cargo shipping used in the empirical part of this research. The following section discusses the results of the network analysis. The conclusion section discusses potential applications, limitations, and directions for future research.

1.2. Theoretical Background

This paper extends two strands of literature: 1) the spatial structures of port systems and 2) network-based regionalization research. While the former provides the theoretical background of port systems, the latter proposes a methodological foundation for applications of the network-based regionalization model to the context of the port system. In this section, the background of each strand is reviewed to draw the hypothesis that forelands and hinterlands of the port system are structured interdependently.

1.2.1. The Spatial Structures of the Port System

The port-hinterland relationship has been studied to address how the economic growth of surrounding urban regions occurs in relation to the functioning of a port system. The classical port development model of Bird (1980) and Taaffe *et al*. (1963) depicts a port system with differentiated spatial structure where locational advantage induces agglomeration of economic activities, urban expansion and economic growth of nearby port areas. The locational advantage of lower freight costs in the vicinity of ports is considered a driving force of the symbiotic relationship between ports and hinterlands, and of business co-location that bolsters urban agglomeration activities near ports (Hesse 2010, Ng *et al.* 2014). In line with this notion, spatial structures of the port system have been captured by simply delineating a port's surrounding region as the port's exclusive service area based on physical proximity (e.g., Niérat 1997).

As the modern international transportation system has advanced, researchers started to question the classical port development model that suggests a simple bilateral landside interaction between ports and hinterlands (see Robinson 1970, Vigarié 1979, Charlier 1992). They argued that spatial dynamics of the port system should be understood in the wider spatial extent framed by shipping flows to and from the ports. In an early study, Robinson (1970) argued that hinterlands and forelands cannot be comprehended separately but are interdependent instead, since shipping flows between hinterlands and ports are part of the whole logistic process spanning across land and water. He observed that destinations of the import flows through Vancouver from Japan were spatially distributed very differently from those from the United Kingdom and those from all other countries. His analysis concluded that the hinterland distribution strongly depends on characteristics and directions of freight flows from forelands.

In the same spirit, Vigarié (1979) proposed the port triptych model to refer to an inseparable relationship between a port, its hinterland and its foreland. The model suggests that depicting the spatial structure of a port system by delimiting a hinterland based on the physical proximity from ports is flawed. Instead, the spatial structure of a port system should regard landside transportation flows to ports as a part of the entire transportation flows across land and water. Charlier (1992) also pointed out that segmenting traffic flows to and from ports may disregard the modern logistic chain, intermodal transport and feedering practices. In sum, ports are no longer viewed as central places connected in simple ways to their hinterlands.

The notion of the port triptych has been further extended in the context of the modern port system as Notteboom and Rodrigue's (2005) conceptual model of port regionalization. Acknowledging the rising importance of inland distribution centers, they argued that port development takes place in a way that port terminals establish integrated network connections with inland ports and distribution services distributed in extensive inland areas. The proposed port regionalization model posits that the spatial extent of the port system goes beyond the vicinity of the ports and can be extended to a wider regional scale. Challenging the hinterland-foreland dichotomy, Rodrigue and Notteboom (2010) extended the port regionalization model to address logistic integration not only on the landside with inland distribution centers but also on the seaside with intermediate hub ports. As hinterlands are structured by regionalization of port terminals and inland distribution centers, they argued that a cluster of ports are also regionalized as a result of the inter-port logistic integration between feeders and hubs on forelands. Considering that containerization and intermodal transportation are strongly linked to the functions of inland distribution centers and hub-and-spoke distribution systems, hinterland-based and foreland-based regionalization are not separate but coupled and interdependent phenomena in effect, as argued by the port triptych thesis (Rodrigue and Notteboom 2010). Monios and Wilmsmeier (2012) argued that port regionalization may take difference forms according to the development strategies of governments, port authorities and maritime and land shipping lines, and according to the institutional relationships between them. Raimbault *et al.* (2016) highlighted the importance of institutional relations of shippers and logistics providers across land and water in creating integrated logistics chain and shaping port regionalization.

Even though there are well grounded theories pointing to port triptych structures as emerging from the contemporary state of the logistic process across sea and land, little empirical validation is so far available. For example, Ducruet and Zaidi (2012) suggested that the emergence of port systems and foreland-side spatial structures can be apprehended by the network structure of inter-port flows, but their study fails to address landside flows and ensuing hinterland-side structures. Guerrero (2014) proposed 4 types of French hinterlands mainly based on the magnitude of how landside transportation flows from hinterlands to ports are diminished by distance, without considering how the shipments forwarded from land are transported on the maritime side. Ducruet *et al.* (2015) proposed a typology of port regions based on local socioeconomic characteristics and ports' commodity specialization with no regard for patterns of land and maritime transportation flows to and from ports. Santos and Soares (2019) presented a methodology for delimiting hinterlands by calculating the minimum generalized costs from load centers to different container terminals, but comprehensive patterns of both maritime and land shipping flows are not considered in their analysis. Thus, even though the port triptych is a well acknowledged concept in international transportation studies, empirical studies have rarely addressed the whole shipping process across land and water.

1.2.2. Network-based Regionalization: Methodological and modeling perspective

The functional regionalization research aims to understand how regions are organized around nodal locales based on socioeconomic and functional relationships between areas (Fox and Kumar 1965, Brown and Holmes 1971, Cliff *et al.* 1975, Haggett *et al.* 1977, Masser and Scheurwater 1980, Hoover and Giarratani 1984, Cliff and Haggett 1998). Spatial structures are captured by discretizing the continuous space into a group of discrete regions and by presenting underlying structures of spatial patterns and socioeconomic relationships, especially highlighting spatial heterogeneity, functional divisions, hierarchies and spatial interactions among the identified regions (Farmer and Fotheringham 2011).

Recent functional regionalization studies have explicitly incorporated the network science approach to better trace spatial structures based on the multi-adic network structures between areas. For example, Farmer and Fortheringham (2011) introduced the network science concepts of modularity and community structures (Newman 2004, 2006) to identify functional regions by qualitatively distinguishing intra- or inter-regional commute patterns. De Montis *et al.* (2013) applied a community detection algorithm to a commute flow network to reveal functional regions that emerge from the human mobility patterns. Community detection algorithms were also adopted to detect functional regional differentiation based on the spatial interaction of mobile phone data (e.g., Gao *et al.* 2013, Sobolevsky *et al.* 2013, Chi *et al.* 2014). Likewise, based on the observation of spatial interactions of social media activities, Shen and Karimi (2016) developed a regionalization method based on multidimensional network measures, and Liu *et al.* (2014) presented a regionalization pattern of the human mobility in China by employing a community detection algorithm. Bergmann and O'Sullivan (2018) used the stochastic blockmodel to detect functional regions formed by the network structures of both migration outflow and inflow patterns between counties. Adopting the network science approach enables to consider network structural features made by flow relationships among more than two entities in the functional regionalization, such as network clustering, centrality, hierarchies, intermediacy, structural equivalence, structural holes, in contrast to more traditional approaches that simply detect bilateral flows between origin and destination areas.

Even though international transportation has rarely been studied from the functional regionalization perspective, there is increasing research that applies the concepts of network science. Ducruet, Rozenblat *et al.* (2010) pointed out that new concepts and methods of network science from physics had not been fully adopted in maritime geography despite the network nature of global maritime shipping. The graph visualization and network-based centrality measures were suggested to address hub-and-spoke structures and port hierarchy in the Atlantic (Ducruet, Rozenblat, *et al.* 2010) and Northeast Asian (Ducruet, Lee, *et al.* 2010) maritime transportation systems. Ducruet and Zaidi (2012) applied the topological decomposition method to the international maritime shipping network and reinterpreted results as the foreland-based regionalization of ports in the context of complex network science. Ducruet and Notteboom (2012) also presented clustering maps and spatial distribution of degree centrality measures of ports at the global scale that show how port systems integrate foreland localities and form foreland-based spatial structures through the global maritime transportation network. The long-term evolution of the maritime transportation systems from 1890 to 2010 is also examined through the single linkage analysis (Ducruet *et al.* 2018). Community detection algorithms were also adopted to explore the hinterland-side regionalization based on the trajectory records of U.S.-bounded export cargo shipping (Jung *et al.* 2018).

To overcome the design limitations of earlier studies, I use the stochastic blockmodeling (SBM) approach to functional regionalization. The SBM shrinks a complex network into a simplified block-to-block network where sets of nodes are reduced to blocks according to similarity in directions and cohesion of network flows. It has been widely used in various studies examining the relational structures in various contexts such as human migrations (Bergmann and O'Sullivan 2018), the global city network (Zhang and Thill 2019) and the brain network (Faskowitz *et al.* 2018). In the context of international transportation, the SBM approach can detect the embedded network structure among groups of origin localities depending on the same port systems, corresponding forwarding ports and intermediate ports. Due to its flexibility in detecting various types of network structures, it can account for the complex functional connections among landside and seaside networks, simultaneously.

1.3. Methods and Data

1.3.1. Data

I take the case of maritime shipping from Europe to the U.S. to study the concept of port triptych. The Port Import Export Reporting Service (PIERS) Trade Intelligence database contains individual records of door-to-door containerized shipping from product sources in Europe to the U.S. ports. Due to their detail in shipping trajectories, PIERS data have been used to investigate port choice patterns of inland cargo shipping in Europe (Kashiha and Thill 2016, Kashiha, Depken, *et al.* 2016, Kashiha, Thill, *et al.* 2016) and in the evaluation of quality of inland transport systems in South America (Tiller and Thill

2015). Through this database, the path of each bill of lading can be tracked down to 4 nodal locations: source of shipping (O), first forwarding port (P1), intermediate port (P2) and U.S. destination port (PUS). These disaggregated trajectories allow me to trace the spatial interaction relationship between forwarding ports, on the one hand, and corresponding source localities in port service areas and transshipment points on the way to the U.S. port of entry, on the other hand.

The dataset includes a variety of shipments that takes different shipping routes and transshipment patterns, but I exclude outlier shipment cases that occur rarely. The outlier cases tend to occur mostly once but have quite peculiar shipping behaviors. In effect, they are akin to noise over which the network model would struggle to maintain its statistical power. Also, since small ports only have very few shipments, it is difficult to precisely capture connectivity patterns in the network. Hence, I filtered out shipment cases that do not directly cross the Atlantic and are transshipped instead at ports in other regions than Europe, such as Asia, South Africa and South America. Because of the peculiarity of the shipping behavior, I also excluded shipment cases from small islands and only included shipment cases that originated from mainland Europe and from British Isles. Shipment cases were also removed if they were shipped through extremely small ports that were found to process only one or two shipments in my original dataset. I filtered out shipment cases if either forwarding or intermediate port is out of the 99.5th percentile by port throughput.

In this research, I use the containerized shipment cases from Europe to the U.S. in October 2006. From an original dataset comprising 106,602 bills of lading, the removal of outliers leaves 103,359 bills of lading, from 12,501 origin localities, 80 forwarding ports, 27 intermediate ports, to 35 U.S. ports of entry. The total shipment volume is 195,921.8 Twenty-foot Equivalent Units (TEUs).

1.3.2. Construction of Sea-Land Shipping Network Data

I compile a shipping network on the containerized shipment data that describes the shipping paths across land and sea (O-P1-P2-PUS). The network data encompass nodes of landside shipping sources and ports links of the landside and maritime shipping flow. The links have three different components[1]: 1) landside shipping flows between source nodes and first forwarding port nodes (O-P1), 2) seaside flows between first forwarding port nodes and intermediate port nodes before cargo departs to U.S. ports (P1-P2) and 3) seaside long-haul trip to a U.S. port (P2-PUS). In case of direct shipping without transshipment, the first forwarding port and the intermediate port are coded identically (P1 = P2).

This leads me to construct two networks based on the respective flow components: the landside shipping network (O-P1) and the maritime shipping network (P1-P2 and P2-PUS). Total cargo shipping is aggregated by origin-destination dyads in these networks. In the hinterland shipping network, I do hexagonal binning of the shipping sources by 25 km radius to standardize their geographical units. Administrative units of each country can be quite varied as they reflect their own socio-political context. Since the geographical scope of this study is that of large economic spaces, using geographically standardized units is an appropriate strategy to avoid the biases associated with the modifiable areal unit problem. The locations of shipping sources are identified by the city names of their shipping addresses, which is prone to deviation from their real production or shipping origins. In

[1] Two types of exceptions do not align with the three components described above. A few cases have a Caribbean port as intermediate port (P2). Then, the P1-P2 segment is a long-haul maritime trip across the Atlantic, and the P2-PUS segment is a short maritime trip between the Carribean and the U.S. Coast.

addition to standardizing geographical units across the European space, the hexagonal binning approach also enables to reduce spatial uncertainty due to the positional errors of geocoding the shipping addresses.

By way of their interface at the ports, the landside and maritime shipping networks are then integrated as a single sea-land shipping network. While numerous source nodes send their shipping to far fewer forwarding ports, ports send or receive shipping according to whether the shipping is transshipped. By this network construction process, I gain a sea-land shipping network with 2,262 nodes and 6,483 links, including 2,143 source nodes, 119 port nodes, 5,569 landside links and 914 maritime links.

1.3.3. Method: Nonparametric Weighted Stochastic Block Model

The SBM is a statistical network model that estimates embedded network block structures by partitioning nodes based on network flow patterns, structural equivalences (topologically similar positions) and community structures marked by strong cohesion among nodes (Karrer and Newman 2011). As a data generalization technique, it can be compared to principal components analysis, which reduces the number of variable dimensions into main principal components, and to cluster analysis, which classifies similar observations with similar scores to the same group. Similarly, the SBM assigns nodes and links in the original network to blocks and block-to-block links in the block network. Since I argue in support of the view that maritime shipping is a hinterland-foreland continuum and in support of the concept of port triptych in the port system (Robinson 1970, Charlier 1992), the SBM is well suited as it offers the advantage of handling all origin-destination links of the shipping trajectories on both hinterland and foreland sides. It assigns each node into a single block based on similarity in their connectivity patterns, each identified block indicates a group of source or port nodes sharing similar landward or seaward shipping patterns in the sea-land shipping network. Thus, the original network with many nodes and links is simplified and reduced to a shrunk network of a reduced number of blocks and between-block links, and the whole network structure is understood with the block-to-block shrunk network. Examining connectivity between the identified blocks helps me to understand components of the port triptych structures.

I adopt the npWSBM proposed by Peixoto (2018), which finds the embedded network block structures based on the quantified strength of the edge weights without prior setting of the number of network blocks. The npWSBM can detect network structures based on not only community structures but also structural equivalences, through which it is possible to find the hierarchy and functional differentiation of ports and the clustering of hinterlands and ports. The network block structure is estimated nonparametrically by finding the optimal partition from the observed hierarchical structure of the given weighted network, unlike the weighted stochastic block model of Aicher *et al.* (2015) that requires the prior setting of the number of blocks (Peixoto 2018). Since shipping from a certain locality may be contested between different ports (Wan *et al.* 2018), I use the containerized cargo volume (TEUs) as the network weight.

Let us consider a global cargo shipping system. It can be represented by a directed graph $G = G(N, \boldsymbol{A}, \boldsymbol{\Omega}, \boldsymbol{b})$ where N is a set of nodes of sources and all ports, $\boldsymbol{A}$ is a binary adjacency matrix whose element $a_{ij} = 0$ or 1 indicates the dyadic connectivity between i and j; $\boldsymbol{\Omega}$ is an edge weight matrix whose element $\omega_{ij} \in \mathbb{R}$ indicates the continuous real weight of a_{ij}, and $\boldsymbol{b}$ is a vector of embedded block memberships of all nodes which are to be determined. The graph $\boldsymbol{G}$ is assumed to be generated conditionally upon the latent block structure:

$$P(\boldsymbol{A}, \boldsymbol{\Omega}|\boldsymbol{b}, \boldsymbol{\theta}, \boldsymbol{\gamma}) = P(\boldsymbol{\Omega}|\boldsymbol{b}, \boldsymbol{\gamma})P(\boldsymbol{A}|\boldsymbol{b}, \boldsymbol{\theta}) \tag{1-1}$$

and

$$P(\boldsymbol{\Omega}|\boldsymbol{b}, \boldsymbol{\gamma}) = \prod_{rs} P(\boldsymbol{\Omega}_{rs}|\boldsymbol{\gamma}_{rs}) \tag{1-2}$$

where $\boldsymbol{\theta}$ and $\boldsymbol{\gamma}$ are two sets of parameters that characterize the probability distributions of a_{ij} and ω_{ij} for all $i, j \in N$, respectively, $\boldsymbol{\Omega}_{rs}$ is an edge weight matrix among nodes in the blocks $\boldsymbol{r}$ and $\boldsymbol{s}$, $\boldsymbol{\gamma}_{rs}$ is a set of parameters that characterize the probability distribution of the edge weights between $\boldsymbol{r}$ and $\boldsymbol{s}$. It should be noted that the weight ω_{ij} is sampled conditionally on $\boldsymbol{\gamma}$ only when the corresponding edge exists. $P(\boldsymbol{A}|\boldsymbol{b}, \boldsymbol{\theta})$ indicates the generation of the unweighted graph based on binary graph connectivity only.

The npWSBM adopts a hierarchical structure in the network blocks (Peixoto 2014). Each node i is nested into level-1 blocks, each of which is again nested into level-2 groups until it reaches level L, which has a single block. Thus, all levels of nodes/blocks are mutually exclusive sets that are exhaustively nested into their higher blocks. The lower block is estimated from the estimated upper block, so it does not require *a priori* setting of the number of blocks. The embedded block structure parameter $\boldsymbol{b}$ can be specified by the following L-level block structure (Peixoto 2018):

$$\boldsymbol{b} \equiv \{\boldsymbol{b}^l\} = \left\{ \left\{ b_i^{(l)} \right\}_l | \ i \in N, l \in \{1, \cdots, N\} \right\} \tag{1-3}$$

where $b_i^{(l)}$ is a block membership of node i at level l such that $b_i^{(l)} \in \{1, \cdots, B_l\}$ and $B_L = 1$. A L-level set of parameters characterizes the edge weight distributions in each block of each level, $\boldsymbol{\gamma} = \{\boldsymbol{\gamma}^l\}$ with $\boldsymbol{\gamma}^{L+1} = \{\hat{\boldsymbol{\gamma}}\}$ being a single hyperparameter at the topmost level. Each $\boldsymbol{\gamma}^l$ is generated by the following probability, conditional to the setting of its higher-level block-to-block graph:

$$P(\boldsymbol{\gamma}^l|\boldsymbol{A}, \boldsymbol{b}^{l+1}, \boldsymbol{\gamma}^{l+1}) = \prod_{rs} P\left(\boldsymbol{\gamma}^l_{rs}|\boldsymbol{A}, \boldsymbol{b}^{l+1}, \boldsymbol{\gamma}^{l+1}_{b_r^{(l+1)} b_s^{(l+1)}}\right) \tag{1-4}$$

where $b_r^{(l+1)}$ and $b_s^{(l+1)}$ denote the $(l+1)$-level blocks to which the l-level blocks r and s belong. Using a nonparametric Bayesian inference approach and a priori hierarchical structure, $\boldsymbol{b}^* \equiv \{\boldsymbol{b}^l\}^*$ can be obtained through maximizing the following Bayesian posterior probability (Peixoto 2018):

$$\{\boldsymbol{b}^l\}^* = \underset{\{\boldsymbol{b}^l\}}{\operatorname{argmax}} P(\{\boldsymbol{b}^l\}|\boldsymbol{A}, \boldsymbol{\Omega}) = \underset{\{\boldsymbol{b}^l\}}{\operatorname{argmax}} \frac{P(\boldsymbol{A}, \boldsymbol{\Omega}|\{\boldsymbol{b}^l\})P(\{\boldsymbol{b}^l\})}{P(\boldsymbol{A}, \boldsymbol{\Omega})}. \tag{1-5}$$

Since $P(\boldsymbol{A}, \boldsymbol{\Omega})$ is not computationally feasible, the optimal solution $\{\boldsymbol{b}^l\}^*$ can be obtained through the Metropolis-Hastings algorithm, which compares the likelihood ratio between two stochastically generated solutions. For detail on the algorithm for the optimal solution, see Peixoto (2018).

1.3.4. Estimation Issues and Determination of the Best-Fit Results

Since the Metropolis-Hastings algorithm uses a random assignment, the npWSBM may generate inconsistent block memberships in each iteration. In order to obtain consistency of the estimation results, I take the block result from the posterior distribution generated from multiple iterations of block results. After running a model 10,000 times to generate the posterior distributions, I obtain a block result by averaging the 10,000 block membership results.

To find the best-fit model that represents the network block structure, I consider six edge weight distributions for the edge weight matrix $\boldsymbol{\Omega}$: normal, log-normal, exponential, Poisson, binomial and geometric distributions. For each weight distribution, I obtain a block result from the 10,000 iterations and measure the goodness-of-fit by the log likelihood scores. Of the six sets of results, I choose the one that gives the highest log-likelihood scores as the best-fit edge weight distribution.

Even though the npWSBM can innately and nonparametrically find the optimal number of blocks, I should consider if the result of the optimal block number is externally valid with regard to spatial distributions of ports and sources. Since the npWSBM only considers network connections between nodes and their structural equivalence, not their spatial locations, it is possible that the results are difficult to interpret if geographically distant nodes (ports or sources) are assigned to the same block. To mitigate this issue, I find the most interpretable network block membership by adjusting the number of blocks around the optimal number and then by visually checking the spatial distributions of block memberships.

1.4. Results

1.4.1. Contextualization of the Network Blocks and Calibration of the Stochastic Blockmodel Results

Of the six edge weight distributions assessed, the log-normal model is found to have the highest log-likelihood values, indicating the best model fit among all edge weight distributions (Table 1-A1). Hence, I choose this distribution for the rest of the analysis. While the global optimal result includes 18 blocks, I check whether this solution is sufficiently interpretable and presents good external validity. In addition, I generate a series of solutions by externally imposing the number of blocks in the range of 10 to 65, and calculate the associated log-likelihood values. The log-likelihood is highest with 18 blocks (123 links), the global optimum (Figure 1-A1). The second and third best solutions are obtained with 20 and 24 blocks (136 and 155 links), respectively.

The three sets of npWSBM results present that source nodes, non-U.S. port nodes and U.S. port nodes are completely partitioned into different blocks; all nodes assigned to each block are the same type. This shows that the npWSBM discerns the difference in connectivity patterns of the three types of nodes: 1) a group of source nodes send shipments to port nodes (dubbed 'hinterland block' hereafter); 2) a group of non-U.S. port nodes receive landside inbound shipments from source nodes and seaside inbound shipments from other port nodes simultaneously, and also send seaside outbound shipments to other port nodes ('port block' hereafter); and 3) U.S. ports only receive maritime shipments from non-U.S. ports ('U.S. port block' hereafter). Given that the whole sea-land shipping network can be split into modules of hinterland, port blocks and U.S. port block, the port triptych structure can be understood as a collection of hinterland, port blocks and U.S. port block and connections between them. Based on the npWSBM results, I can further categorize three types of port blocks: *feeder*, *hub* and *gateway* blocks (Detailed characteristics of three types of port blocks are described later). The schematic illustration of hinterland, port and U.S. port blocks consistent with this conceptualization is presented in Figure 1-1.

The global optimal log-normal model identifies 18 blocks embedded in the Europe-U.S. freight shipping network, 6 hinterland blocks, 11 port blocks and 1 U.S. port block. The spatial representation of the npWSBM results presents hinterland and port blocks with their geographical extent and shipping characteristics (Figure 1-A2). Despite having the

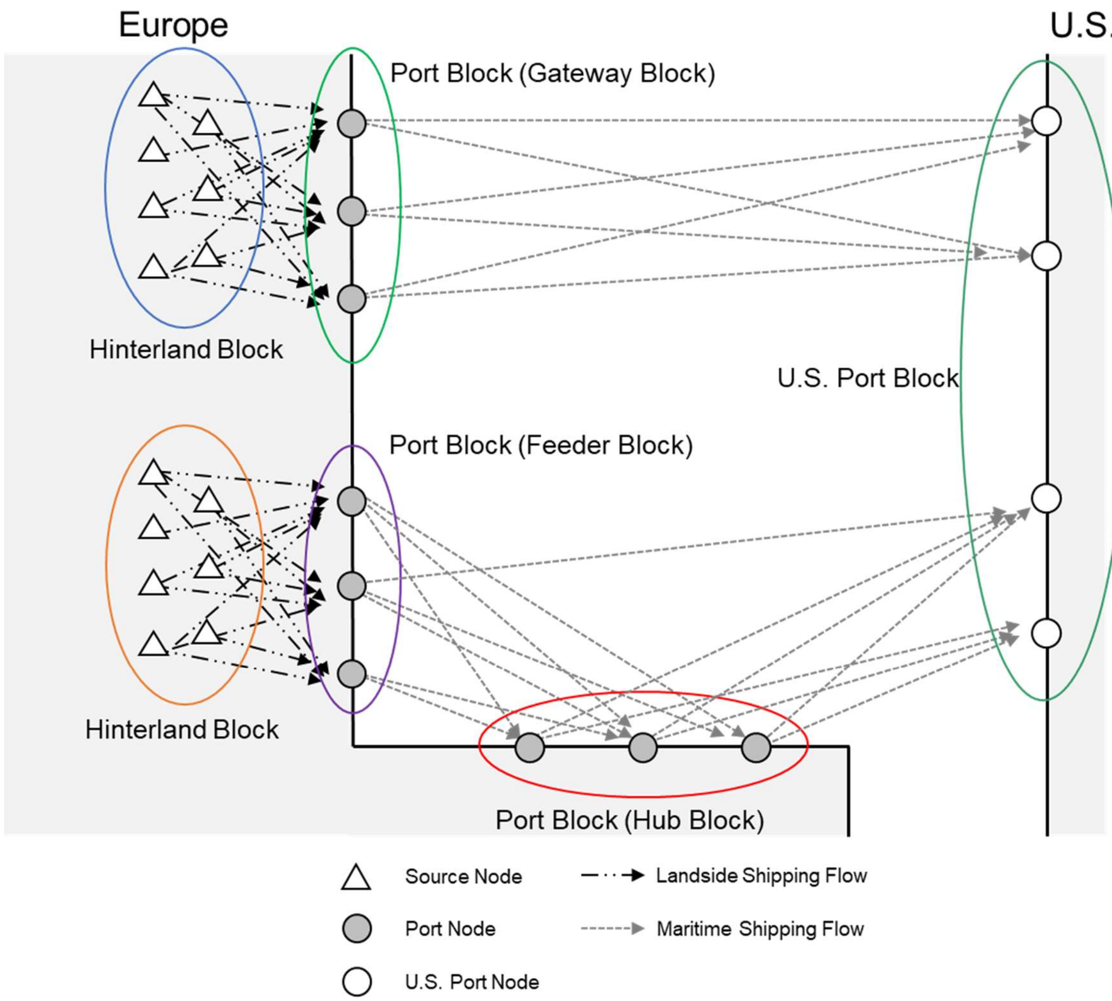

Figure 1-1 Schematic hinterland, port and U.S. port blocks in the sea-land shipping network

highest log-likelihoods, I find that the solutions with 18 and 20 blocks are limited in representing the full reality of the European port system, especially in its eastern part (Figure 1-A2). Even though these results are the two best from a statistical criterion perspective, their poor ability to depict that Balkan and Baltic ports are physically separate and that they constitute different port systems in the East Mediterranean and Baltic seas lead me to turn to the third optimal solution, which encompasses 24 blocks, as the solution worthy of consideration for the rest of my analysis. This solution identifies 9 hinterland blocks (blocks A–I), 14 port blocks (block 1–14) and 1 U.S. port block (block 15) (Figure 1-2). Balkan and Baltic ports are assigned to distinct port blocks 2 and 3, respectively, and the eastern landside areas are split into Balkan (block A) and Baltic areas (block B). This provides more interpretable results where I can capture the spatial structure between hinterland, forelands and ports more meaningfully.

As a final step, I check if the detected port blocks have sufficient cohesion without any outlier nodes. I measure the cosine similarity in the block-to-block connection between each port node and their assigned block to see if individual port nodes have significantly different connectivity patterns from those of the block they are assigned to. The cosine similarity is 0 when a port node has a connectivity pattern uncorrelated with that of their assigned block; it is 1 when a port node has a perfectly correlated connectivity pattern. All port nodes, except Bordeaux and Newcastle, have a cosine similarity above 0.5, indicating a high level of cohesiveness to the assigned block. Bordeaux and Newcastle have low cosine similarity scores (0.146 and 0.367, respectively) that indicates that they have a significantly different and peculiar connectivity pattern from the rest of their block. Hence, Bordeaux and Newcastle are excluded from their block membership and are left as unassigned isolate nodes (block 16).

1.4.2. Characteristics of Hinterland and Port Blocks

In the 25-block solution, 9 hinterland blocks each encompass areas that source freight shipments with similar connectivity patterns to ports (Figure 1-2). The whole European economic space is partitioned into 9 hinterland areas, including the Balkans (A), Baltic-Scandinavia (B), Italy, (C) Northern Italy (D), Netherlands-West Germany (E),

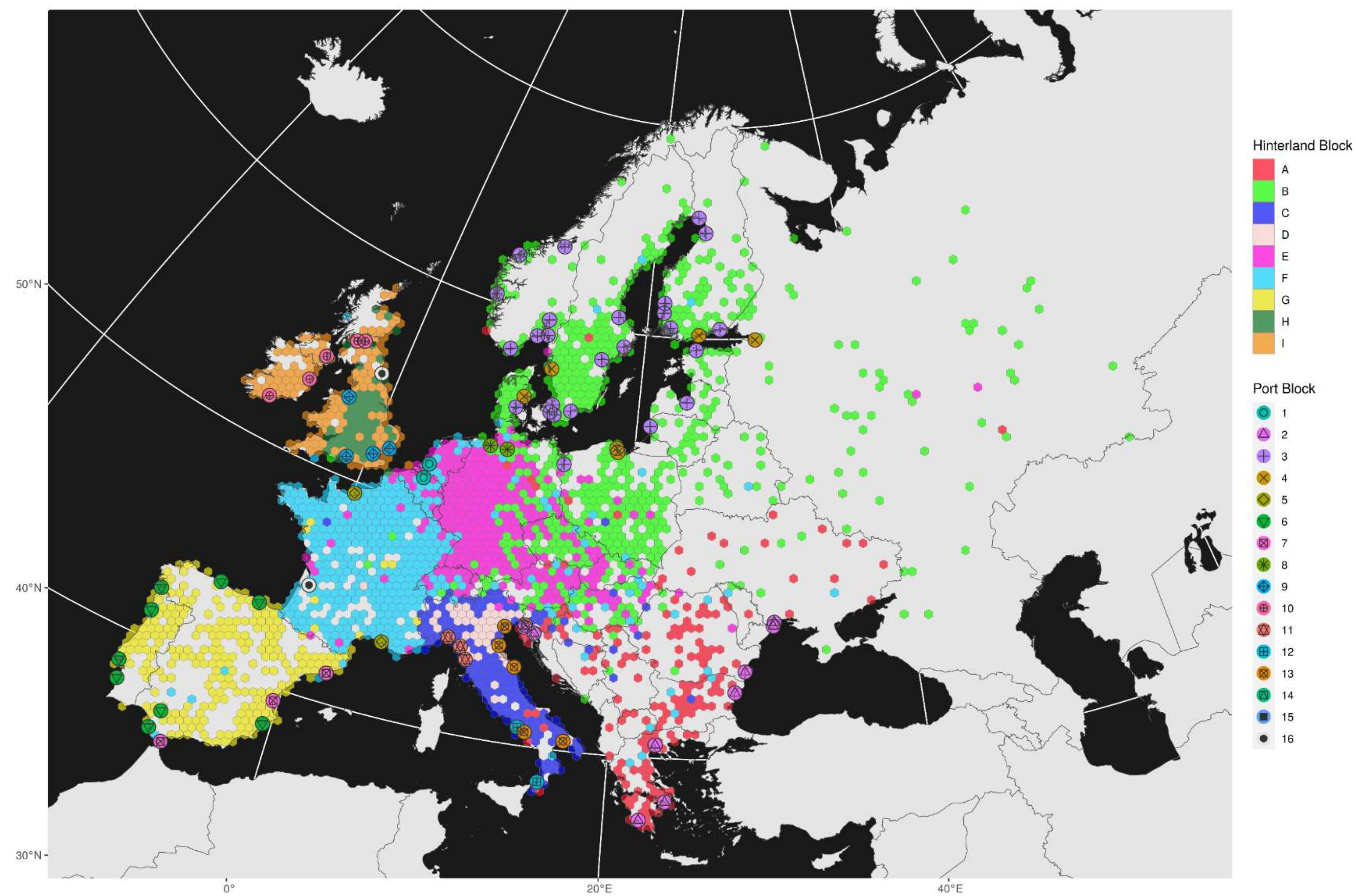

Figure 1-2 Spatial representation of the hinterland and port blocks from the final stochastic block modeling results (25 blocks) (Note: Land areas with no color indicate that no shipment is sourced from those areas. Shipments from small islands are excluded from the analysis)

Table 1-1 Hinterland blocks from the final stochastic block modeling results

Hinterland Block	Area	Total Shipment [TEUs]	Transshipment [TEUs]	Transshipment Rate
A	Balkans	3,545.19	2,551.34	**71.97%**
B	Baltic-Scandinavia	23,347.24	16,416.76	**70.32%**
C	Italy	9,803.62	1,738.6	17.73%
D	Northern Italy	26,918.34	2,672.45	9.93%
E	Netherlands-Western Germany	70,197.74	2,901.38	4.13%
F	Belgium-France	28,407.84	3,046.31	10.72%
G	Iberia	15,138.99	5,308.87	35.07%
H	British Isles	13,878.75	1,884.65	13.58%
I	British Isles	4,684.09	2,551.64	**54.47%**

Belgium-France (F), Iberia (H) and British Isles (H, I). Table 1-1 shows each hinterland block's detailed profile, including total freight volume, total transshipment volume and transshipment rate. Many hinterland blocks align with country borders, while blocks A, B and E span multiple neighboring countries. This indicates that freight logistics in countries like France, United Kingdom, Ireland, Portugal, Spain and Italy are processed mostly at the domestic level or within two adjacent countries, but shipments from Balkan, Baltic and Scandinavian countries depend on cross-country inland transportation for freight shipping. The high rates of transshipment for shipments from blocks A and B also indicate that these areas have limited access to direct shipping line services for export shipments to the U.S. but depend on other hub functions in other countries.

Each port block encompasses a group of ports that have similar landward and seaward shipping flow patterns. Hence, the existence of these port blocks points to a systematic order in port nodes at the interface between hinterlands and forelands. These blocks, therefore, empirically corroborates the soundness of the concept of port triptych and demonstrate its staying power in the contemporary international port system. Characterization of these blocks will enable us to better understand the contemporary modalities of the organization of the hinterland-to-foreland continuum. These results identify 14 port blocks that serve different coastal areas of Europe: Antwerp-Rotterdam (1), Balkans (2), Baltic-Scandinavia (3, 4), France (5), Iberia (6, 7), Hamburg-Bremerhaven (8), British Isles (9, 10) and Italy (11, 12, 13). Remotely located offshore ports (14) and U.S. ports of entry (15) are identified as separate blocks that fall outside of the map. Due to their low cosine similarity scores, Bordeaux and Newcastle are classified as isolate ports (16), Table 1-2 shows each port block's detailed profile, including the total landside inbound shipment volume, landside inbound transshipment volume, total seaside outbound shipment volume, seaside outbound transshipment volume and transshipment rates and the relative rate, which indicates that the ratio of the block's transshipment rate to that of the whole Europe. The block membership is listed in Table 1-3. Each foreland block is found to have distinct shipping flow patterns, mainly indicated by the proportion of outbound and inbound transshipments.

As shown in Figure 1-1, I categorize the port blocks by their role in the whole shipping network based on the preponderance of transshipment activities. The following conventions are used. When a block's ports receive and forward landside freights to other ports for transshipment more frequently than the average (19.94%), they can be considered *feeder* block. If a block's ports receive and transfer maritime freights to U.S. ports of entry more frequently than the average, I define the block as a *hub* block. When a block transfers

Table 1-2 Port blocks from the final stochastic block modeling results

Port Block	Area	Role	Inbound Landside Shipment				Outbound Maritime Shipment to U.S. Ports			
			Total [TEUs]	Transshipment [TEUs]	Transshipment Rate	Relative Rate	Total [TEUs]	Transshipment [TEUs]	Transshipment Rate	Relative Rate
1	Antwerp-Rotterdam	Gateway Hub	53,194.14	1,137.74	2.14%	0.11	58,120.32	6,063.92	10.43%	0.52
2	Balkans	Feeder	4,233.70	3,554.84	83.97%	**4.21**	861.52	182.66	21.20%	**1.06**
3	Baltic-Scandinavia	Feeder	6,628.73	6,628.73	100.00%	**5.01**	0	0	0.00%	0.00
4	Baltic-Scandinavia	Feeder	11,333.44	9,950.13	87.79%	**4.40**	1,652.26	268.95	16.28%	0.82
5	France	Gateway	13,837.63	1,866.63	13.49%	0.68	13,161.14	1,190.14	9.04%	0.45
6	Iberia	Feeder	5,894.73	4,771.08	80.94%	**4.06**	1,920.21	796.56	41.48%	**2.08**
7	Iberia	Hub	9,956.79	1,120.67	11.26%	0.56	13,271.76	4,435.64	33.42%	**1.68**
8	Hamburg-Bremerhaven	Gateway Hub	36,075.31	1,547.51	4.29%	0.22	49,335.97	14,808.17	30.01%	**1.51**
9	British Isles	Gateway	14,562.46	825.10	5.67%	0.28	15,422.63	1,685.27	10.93%	0.55
10	British Isles	Feeder	3,609.75	3,609.75	100%	**5.01**	0	0	0.00%	0.00
11	Northern Italy	Gateway	30,403.52	2,077.07	6.83%	0.34	29,491.15	1,164.70	3.95%	0.20
12	Italy	Hub	4,797.91	589.06	12.28%	0.62	7,671.50	3,462.65	45.14%	**2.26**
13	Italy	Feeder	1,393.69	1,393.69	100.00%	**5.01**	0	0	0.00%	0.00
14	Outside of Europe	Offshore Hub	0	0	0.00%	0.00	5,013.34	5,013.34	100.00%	**5.01**
15	The whole Europe	-	195,921.8	39,072	19.94%	1.00	195,921.8	39,072	19.94%	1.00

Table 1-3 Port block membership

Block	Area	Role	Ports
1	Antwerp-Rotterdam	Gateway Hub	Antwerp, Rotterdam
2	Balkans	Feeder	Varna, Rijeka, Kalamata, Piraeus, Thessaloniki, Constanta, Koper, Illyichevsk, Odessa
3	Baltic-Scandinavia	Feeder	Copenhagen, Fredericia, Tallinn, Kemi, Oulu, Mantyluoto, Rauma, Turku, Kotka, Riga, Klaipeda, Trondheim, Aalesund, Bergen, Kristiansand, Larvik, Oslo, Fredrikstad, Szczecin, Helsingborg, Malmo, Ahus, Norrkoping, Stockholm, Gavle
4	Baltic-Scandinavia	Feeder	Aarhus, Helsinki, Gdansk, Gdynia, St Petersburg, Gothenburg
5	France	Gateway	Le Havre, Fos
6	Iberia	Feeder	Leixoes, Lisbon, Sines, Bilbao, Gijon, Vigo, Seville, Cadiz, Alicante
7	Iberia	Hub	Algeciras, Valencia, Barcelona
8	Hamburg-Bremerhaven	Gateway Hub	Hamburg, Bremerhaven
9	British Isles	Gateway	Tilbury, Felixstowe, Liverpool, Southampton
10	British Isles	Feeder	Cork, Dublin, Grangemouth, Glasgow, Belfast
11	North Italy	Gateway	Genoa, La Spezia, Leghorn
12	Italy	Hub	Naples, Gioia Tauro
13	Italy	Feeder	Salerno, Taranto, Ancona, Ravenna, Venice, Trieste
14	Outside of Europe	Offshore Hub	Freeport (Bahamas), Caucedo (Dominican Republic), Haifa (Israel), Kingston (Jamaica)
15	U.S. Ports	-	New Westminster (Canada), Vancouver BC (Canada), Cleveland, Portland, Boston, New York, Perth Amboy, Chester PA, Philadelphia, Baltimore, Norfolk, Newport News, Richmond VA, Wilmington NC, Charleston, Savannah, Jacksonville, Palm Beach, Port Everglades, Miami, Tampa, Mobile, New Orleans, Beaumont, Galveston, Houston, Long Beach, Los Angeles, Port Hueneme, San Francisco, Oakland, Vancouver WA, Seattle, San Juan, Honolulu
16	Isolates	-	Bordeaux, Newcastle

both landside and maritime freight less frequently than the average, the ports forward shipments directly to U.S. ports of entry, and I call the block a *gateway*. Considering that the ports of Antwerp and Rotterdam (block 1) transfer substantial amounts of maritime shipments from other ports to U.S. ports (15.52% of the total transshipments), and that Hamburg and Bremerhaven (block 8) forward significant amount landside freights directly to U.S. ports of entry, the blocks 1 and 8 are considered to have characteristics of both gateway and hub, so they are classified as a *gateway-hub* blocks. Because of the geographical remoteness from Europe, I categorize the ports in block 14 as *offshore hubs*.

1.4.3. The Network Block Structure of the Port System

I now examine how hinterland and port blocks are integrated in the sea-land shipping network and constitute the whole port system in Europe. To this end, nodes and links are aggregated by blocks, and the node-level network is reduced to the block-level shrunk network (Figure 1-3). The visualization of the block-level shrunk network leads a number of findings about the spatial structure of the port system in Europe.

First, I can find that trade shipments are structured via the dominant role of a few large port blocks. In my dataset of U.S.-bound shipments, the U.S. ports receive 69.9% of the total shipment volume from port blocks 1, 8 and 11 as the last port of export, including Antwerp, Rotterdam (block 1); Hamburg, Bremerhaven (block 8); Genoa, La Spezia and Leghorn (block 11). This is not just because these blocks process landward shipments from their own hinterlands, like blocks D, E and F, but also process cargo transshipped through other feeder blocks. Especially, blocks 8 and 11 are found to be main intermediate nodes between U.S. ports, feeders and hinterlands, indicating their critical role as a hub in the European port system.

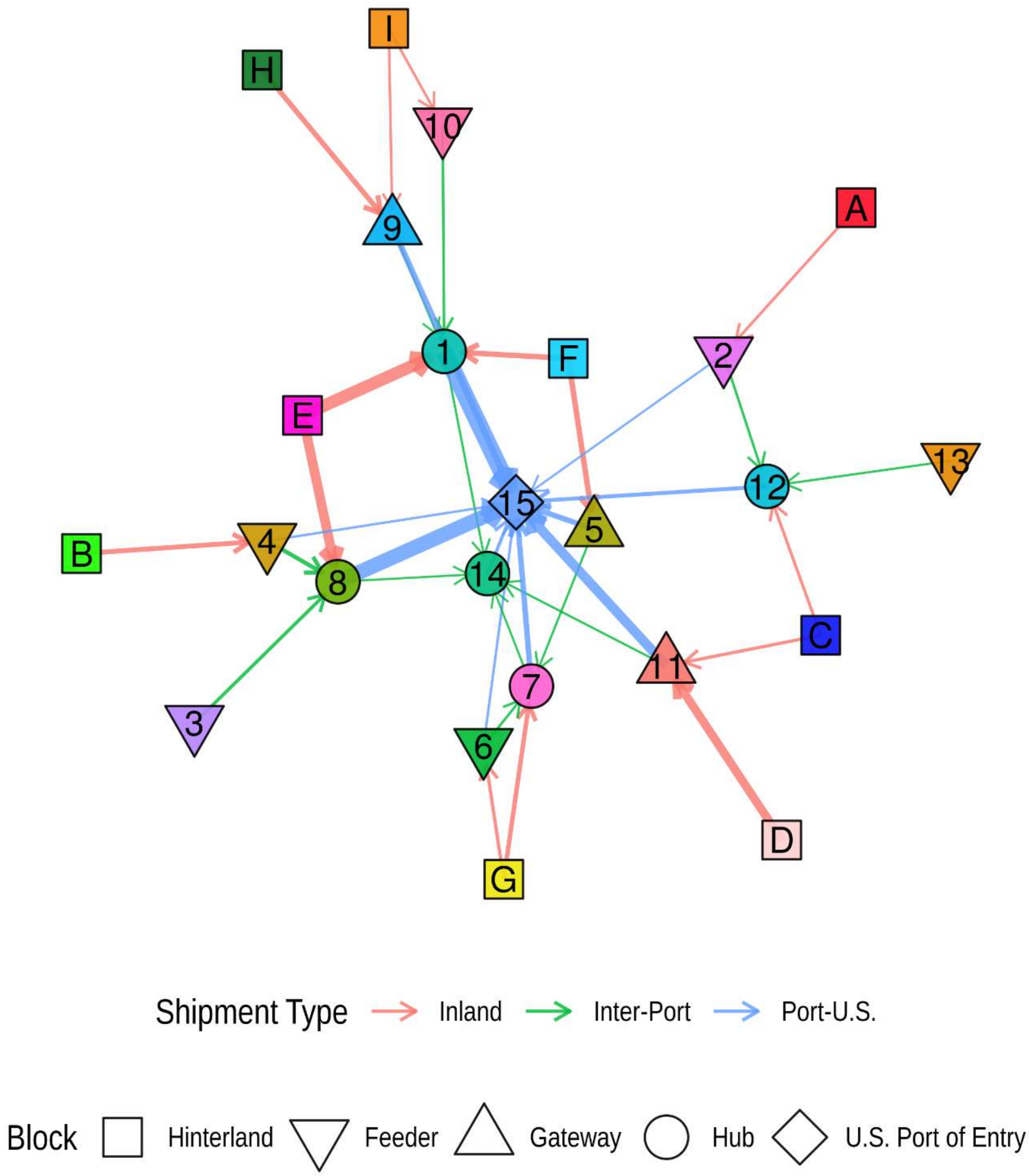

Figure 1-3 The block-level shrunk network of the sea-land freight shipping system of Europe. Squares, circles, triangles, and diamonds stands for blocks of diverse types. They are labeled according to the lists in Tables 1 and 2. (Note: The network is visualized with Fruchterman-Reingold layout)

Second, Europe's trade logistics is driven by the hub-and-spoke system where a few hub ports and many feeder ports hold complementary functional division. The node-level shrunk network (Figure 3) shows a functional division in the trade logistics between a few hubs and many feeders represented by the block-to-block connection. I find hub or gateway blocks (1, 7, 8, 11, 12 and 14) near the center of this network (block 15), which stands for the whole set of U.S. ports of entry to which they have direct shipping lines. I also find feeder blocks (2, 3, 4, 6, 10 and 13) placed at the periphery around the corresponding hub blocks, whose feeder operations are tied to. The hub blocks do not only serve hinterland blocks but they also mediate shipments between U.S. ports and feeder blocks as maritime transshipment points. In contrast, the feeder blocks are positioned between hinterland blocks and hub blocks, indicating a role in providing feeder operations that forward shipments to hub ports. The connection among feeder and hub blocks shows how feeder and hub ports maintain a complementary multi-adic relationship via the logistic integration for the whole shipping process.

Third, while some hinterland areas have direct access to the shipping lines to U.S. ports, others have indirect access through the feeder ports. Hinterland blocks D, E and F maintain a strong tie to hub or gateway blocks directly connected to the U.S. ports (11, 1, 5 and 8); on the other hand, hinterland blocks at the periphery (A, B, G and I) of the shrunk network are mainly connected to feeder blocks, not hub nor gateway blocks. The former hinterlands are the areas where direct shipping line services to the U.S. are provided, but the latter hinterland blocks have limited direct access to the shipping lines to the U.S.; thus, most of their shipments can reach U.S. ports through transshipment via feeder and hub blocks. Hinterland blocks A, B, G and I are direct hinterlands of the feeder blocks 2, 4, 6 and 10, respectively, but at the same time, also can be considered as indirect hinterlands of the hub blocks 12, 8, 7 and 1, respectively, because their shipments to the U.S. should be transshipped through those hub blocks.

1.4.4. Block-to-Block Trajectory and Hinterland-Foreland Continuum

Adopting the concepts of hinterland-foreland continuum (Robinson 1970) and port triptych (Vigarié 1979), I examine the entire trajectory of all shipments across land and water to comprehend the foreland-hinterland continuum structure of the European port system. On the aggregate, I track the block-level shipment flows departing from each hinterland and their flow patterns throughout the shipping trajectory from sources to U.S. ports of entry. By matching each of the 4 nodal locations (O-P1-P2-PUS) in the shipments' sequence to their assigned block, I produce an alluvial plot that tracks block-to-block shipment flows (Figure 1-4). The group of flows departing from each hinterland block is color-coded to trace patterns through *en route* nodal points to the final U.S. ports of entry. Direct and transshipped shipments are separated to better illustrate flow patterns. Based on the block-to-block shipping trajectory patterns, the hinterland-foreland continuum structures in the European economic space are described as follows.

Block A (Balkan area) is the area mainly served by the hub-and-spoke distribution system of Naples-Gioa Tauro, where port blocks 2 and 12 work together in the East Mediterranean area. Since the ports on the Balkan coast lack long-haul shipping lines to the U.S., the shipments exhibit patterns of being first forwarded to the feeder ports in block 2, and then transferred to the hub ports in block 12. Even though Naples and Gioa Tauro (block 12) are located in Italy and are topographically separated from the block A, they are transit points on the maritime routes to the U.S. and have a locational advantage in being a hub port for shipments sourced from block A.

Block B (Baltic-Scandinavia) depends on the hub-and-spoke distribution system of Bremerhaven-Hamburg (block 8) interfaced with port blocks 3 and 4 to serve the Baltic

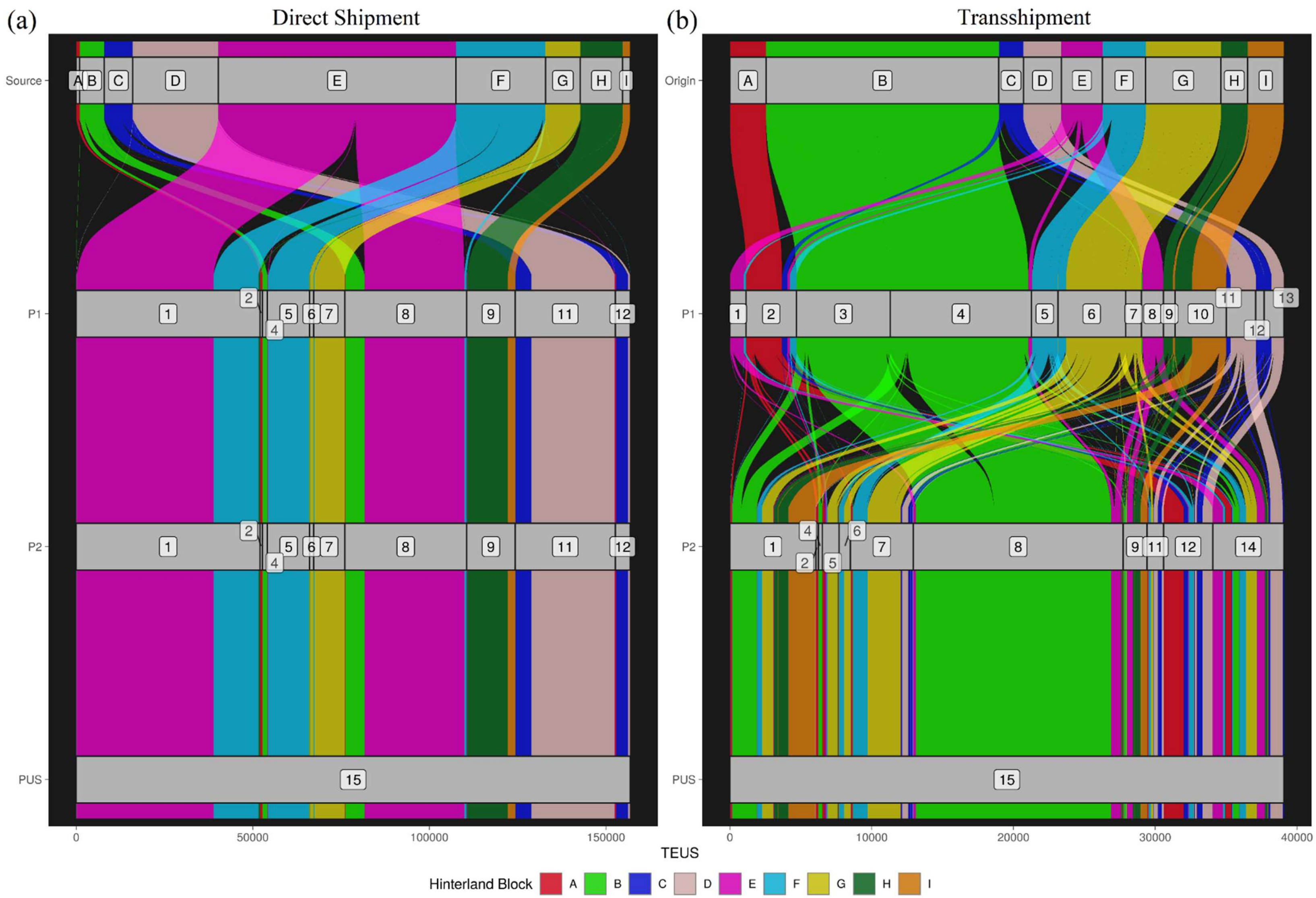

Figure 1-4 Alluvial plot of block-to-block shipment flows: (a) Direct Shipment Flow, (b) Transshipment Flow

Sea area. Freight flows from block B account for the largest share of the total transshipments handled by the latter two blocks. While very few shipments are directly shipped to the U.S. through ports in blocks 4 and 8 (Figure 1-4-(a)), most shipments are shipped by the feeder operations of blocks 3 and 4 and then transshipment at Bremerhaven or Hamburg (block 8). The ports in both blocks 3 and 4 are primarily dedicated to feeder operations exclusively for connecting block A and Bremerhaven-Hamburg. Given that a few shipments are directly shipped through ports in block 8, the latter plays a very limited role as a local hub by providing long-haul shipping lines to the U.S.

Block C (Italy) covers a hinterland area that generates a smaller amount of shipments than block D. This area does not depend on a single shipping channel to the U.S., so the hinterland-foreland structure is quite complex. A small volume of shipments are directly forwarded to the U.S. through Genoa-La Spezia-Leghorn (block 11) and Naples-Gioia Tauro (block 12). As for block A, this area also depends on a shipping process through the hub-and-spoke distribution systems of Genoa-La Spezia-Leghorn (block 11), supported by the feeder operations of blocks 12 and 13, and Naples-Gioia Tauro (block 12), supported by block 13.

Italy's Northern industrial areas (Block D) shows a direct hinterland area exclusively served by Genoa-La Spezia-Leghorn (gateway block 11). While a few shipments are processed through transshipment from block 11 to 14 and from 13 to 12, the dominant volume of shipments are directly shipped through block 11. The port functions of Genoa-La Spezia-Leghorn work as a main gateway for block D by exclusively providing a direct access to shipping lines to the U.S. without the need for transshipment.

The Netherlands and Western Germany (Block E) constitute a direct hinterland area of two main gateway-hub blocks, namely Antwerp-Rotterdam (block 1) and Bremerhaven-Hamburg (block 8) (Figure 4(a)). Placed between the two gateway-hub blocks, this area has a high level of direct access to the two port blocks' direct shipping lines to the U.S.; very little of its freight is transshipped. Benefitting from this great accessibility advantage, this area is found to generate the largest shipment volume to the U.S. of all hinterland blocks. Given that the shipping flows are bifurcated to two streams into the two gateway-hub blocks, this area is an overlapping hinterland where those gateway-hub ports fiercely compete with each other.

Block F (Belgium-France) marks a direct hinterland area served by Antwerp-Rotterdam (block 1) and Fos-Le Havre (block 5) that provide direct shipping lines to the U.S. A few shipments confined to the Western Mediterranean are observed to be transferred between blocks 5 and 7, where Fos serves as a feeder port towards the three large Spanish hubs, but the amount is not significantly large. This block is the area where four main gateway ports compete and attract shipments from different directions: Le Havre attracts shipments from the North, Fos from the South, and Antwerp-Rotterdam in the Northeast. Despite the small amount of transferring shipments, similarly to block E, this area can be considered an overlapping hinterland of Antwerp-Rotterdam (block 1) and Fos-Le Havre (block 5).

Shipments from block G (Iberia) depend on the complementary operation of port blocks 6 and 7, distributed along Spanish and Portuguese coastline. Similar to the block C, there are multiple shipping channels to the U.S., and the hinterland-foreland structure is complex here too. The shipments are both directly shipped and transferred through feeder-hub connections. While the direct shipments tend to sail through Algeciras-Valencia-Barcelona (block 7), large hub ports in the Western Mediterranean, shipments that are transshipped have a pattern of first being forwarded to feeder ports in block 6 and then transshipped at the hub ports in block 7. Limited cargo is transferred at other port blocks, namely 1, 5 and 14. Thus, block G is integrated with the hub-and-spoke system of Algeciras-Valencia-Barcelona where block 6 offers feeder operations and block 7 provides a hub function.

Similar to block G, the shipments from blocks H and I (British Isles) are both directly shipped and transferred through feeder-hub connections. Block H mainly serves as the direct hinterland area of block 9, while block I represents a hinterland area served overwhelmingly by the feeder operation of block 10 and the hub function of Antwerp-Rotterdam (block 1). While block 10 is dedicated to feeder operations in the British Isles (Figure 4(b)), block 9 assumes the role of local hub by providing long-haul shipping services and processing shipments transferred from block 10. However, a dominant share of the transferring shipments is processed through non-local hub ports, Antwerp-Rotterdam (block 1), rather than domestic local hub ports in block 9. Thus, block H depends on block 9 for direct long-haul shipping service to the U.S., while block I is part of the hub-and-spoke distribution system of Antwerp-Rotterdam, where block 10 provides feeder service.

1.5. Conclusions

As international freight shipping technologies went through major leaps forward over the past two decades, spatial interactions of international freight transportation can no longer be regarded as a simple dyadic relationship between ports and their hinterlands. The multiple logistic processes enabled by cargo containerization and intermodal integration and transshipment have added more complexity in comprehending flow patterns and spatial structures of port systems. This study aimed at studying spatial structures of a port system by addressing integrated landside-seaside freight flow dynamics with micro-level trajectory records of export cargo shipping.

This work makes theoretical and methodological contributions to the domain of international freight transportation research. I addressed complex flow behaviors of modern freight shipping and provided empirical validation to support contemporary discussions on spatial structures of port systems. By adopting the npWSBM model of network science and tracing patterns of the whole trajectory of freight shipping, I substantiated the conceptual frameworks of port triptych (Vigarié 1979) and hinterland-foreland continuum (Robinson 1970) on a large dataset of sea-land shipping records. The block structures identified by the npWSBM in the sea-land shipping network have brought to light various hinterland-foreland continuum structures in Europe and the fundamental interdependency between hinterlands and forelands. Ports were classified to the same block by their functions in the whole logistic process, such as feeder or hub operations, and their geographic expression was found to align well with logistical practices. Feeder, gateway and hub port blocks complement each other's functions in the whole logistic process and, together, delineate logistically coherent hinterland areas. Thus, the hinterland areas are not just limited by the local vicinity of ports where shipments are first forwarded, but by the range of the hub-and-spoke shipping network of hub ports. The network-based view espoused in this analysis enhances my understanding of hinterland-foreland continuum structures that arise when landward and seaward shipping flows are regarded together.

The network-based analysis sheds new light on port-driven regional development policies by materializing the hinterland-foreland continuum perspective. Still many maritime transportation policies separately regard either landside transportation corridor development or seaside shipping line service. My analysis can help policymakers to establish a comprehensive transportation development strategy that simultaneously relates inland transportation corridors to good maritime accessibility (Notteboom and Rodrigue 2005). By capturing closely related hinterland and foreland regions and their hinterland-foreland continuum structures, policymakers can better understand a geographical scope of freight transportation flows, better promote the coordination between inland and maritime transportation development, and foster the building of sea-land transportation governance between local governments, shipping line companies and port authorities across different countries (Notteboom and Rodrigue 2005, Wilmsmeier *et al.* 2011, Notteboom *et al.* 2013). Based on the understanding of the hinterland-foreland continuum structures, entities of local governments and port authorities can pursue extra-local economic cooperation beyond the ports' vicinity to combine inland transportation development and maritime deep-sea service (Hall and Jacobs 2010).

However, I acknowledge some of the limitations of this research. Due to lack of access to data, my analysis only covers U.S.-bound outgoing freight shipping flows. Accordingly, my results represent only a fraction of Europe's freight flows, so the spatial structures identified may not reflect the full substance of Europe's port system and may not show the whole hinterland-foreland continuum structures in Europe. For example, shipments departing from Northern Italy to China are likely to cross the Suez Canal, so their flow patterns across land and sea would be much different from those of the cross-Atlantic shipments depicted here.

Also, my analysis does not consider commodity types of shipments. It is true that different hinterland areas have specialized local industries and freight shipping behaviors must be tied to the type of goods for export. This is likely to affect the relationship between hinterlands and ports and resulting hinterland-foreland structures. Since existing stochastic block models only consider connectivity between nodes and the flow intensity (freight volume), it is not yet possible to explicitly treat qualitative characteristics of the flow like commodity types. Future developments in stochastic block modeling in this direction may expand the use of network-based functional regionalization to examine how hinterland-foreland structures depend on the commodity specialization of ports.

Lastly, expanding this analysis to other world regions would allow to scale up to the world's port system as a whole. Important questions such as whether the properties identified here for Europe are universal, or whether other forms of organization may emerge under diverse degrees of freedom of freight movements across borders, diverse levels of economic and logistic integration, and diverse landscapes of economic advancement. Along the same line, a longitudinal analysis would underscore the critical role that long-term changes in the economic, trade, and technology contexts may have on the adaptation of hinterland-foreland continuum structures.

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APPENDIX: SUPPLEMENTARY FIGURES AND TABLES

Table 1-A1 Results of the nonparametric weighted stochastic block models with different edge weight specifications

Edge Distribution	Number of Network Blocks	Log Likelihood
Normal	27	-56080.943
Log Normal	18	-48650.335
Exponential	28	-48536.192
Poisson	86	-69325.691
Binomial	103	-68543.009
Geometric	27	-49053.240

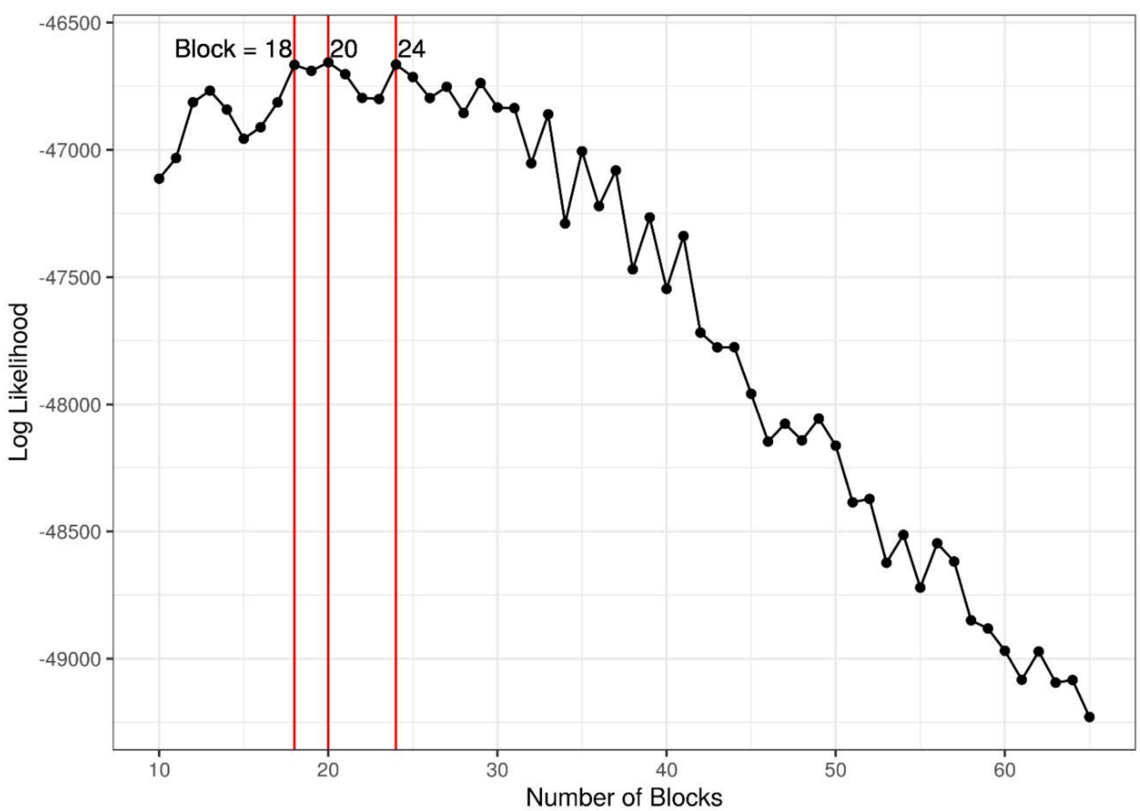
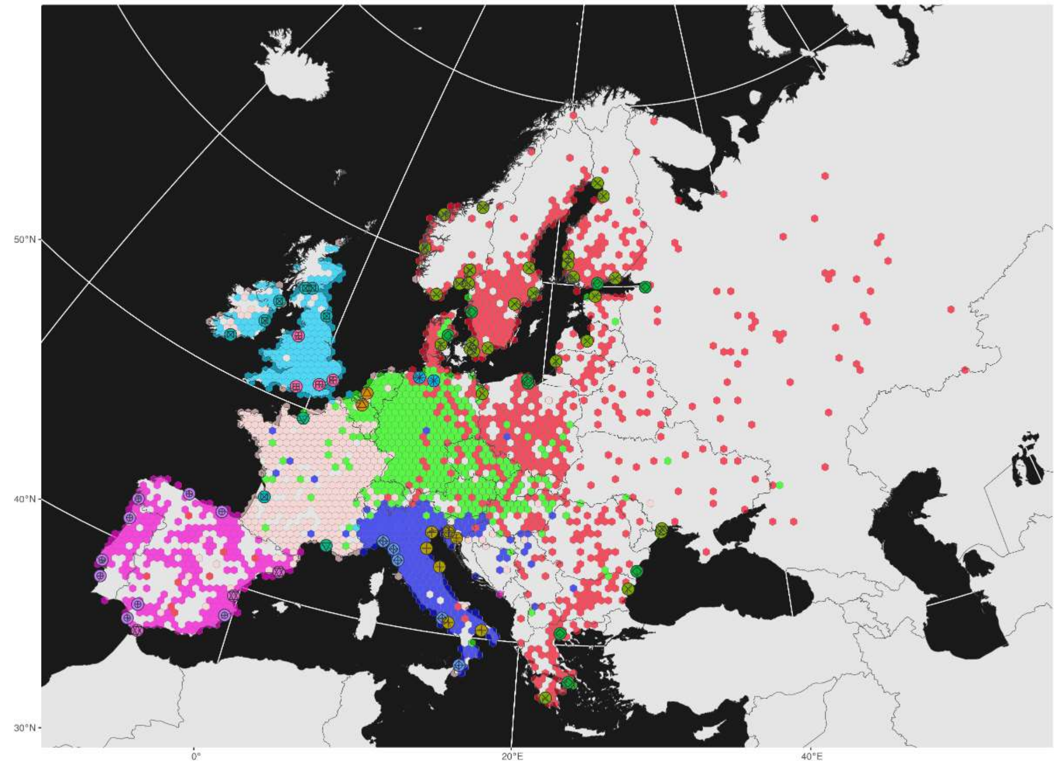


Figure 1-A1 Block number and log-likelihood scores of the log-normal stochastic blockmodeling results

(a)



(b)

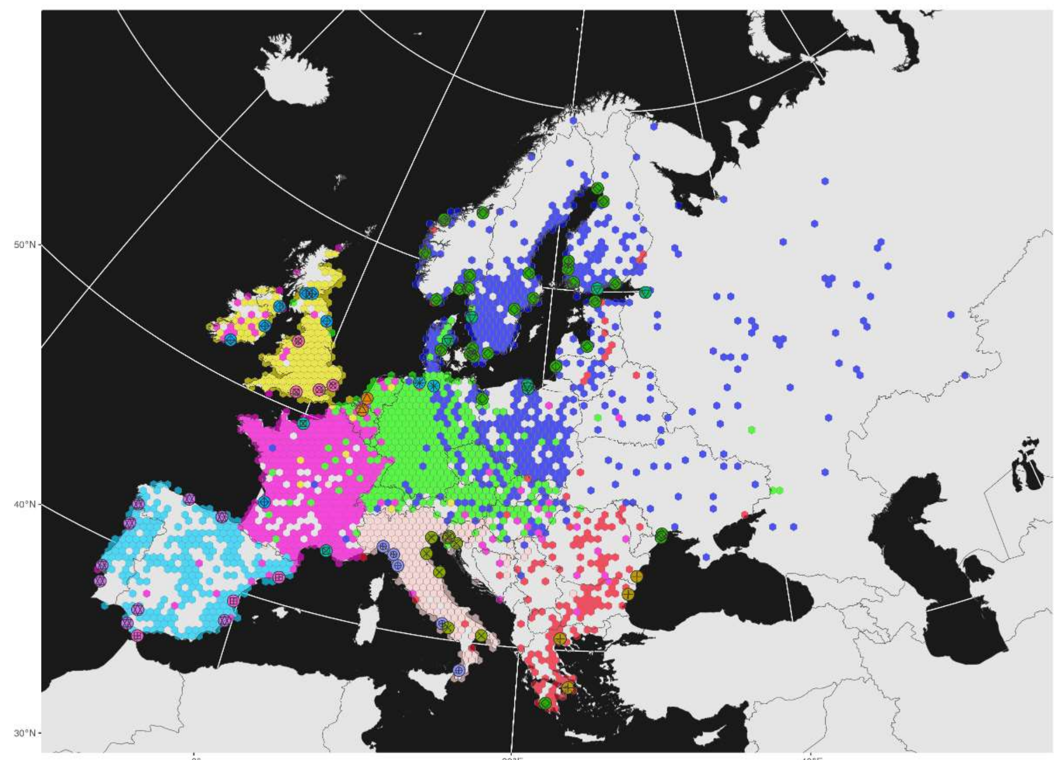


Figure 1-A2 Spatial representation of the stochastic block modeling results color-coded by blocks: (a) the global optimal result (18 blocks); (b) the second optimal result (20 blocks).

CHAPTER 2: GLOBAL SHRINKAGE OF SPACE AND THE HUB-AND-SPOKE SYSTEM IN THE GLOBAL TRADE NETWORK

2.1. Introduction

Presented by Tobler (1970) as "the first law of geography", the inverse relationship between distance and spatial interaction of commerce has been posited as a central paradigm in economic geography (Thill 2011). For research intent on substantiating the true nature of this relationship, economic globalization has been held as a case in point. Distance has been reported to have its influence fade over time as evidenced by the sharp drop in long-distance shipping costs that has accompanied advances in transportation and information systems (Coe *et al.* 2007, Buch *et al.* 2004, Glaeser and Kohlhase 2004, Knowles 2006, Bleaney and Neaves 2013). Cairncross (1997) went as far as proclaiming the "death of distance." At the same time, others have presented refuting evidence that the distance effect is still quite strong (e.g., Rietveld and Vickerman 2004, Carrère and Schiff 2005) and even has increased over time (e.g., Berthelon and Freund 2008, Disdier and Head 2008, Head and Mayer 2013); they have dubbed it "the missing globalization puzzle" or "distance puzzle." Furthermore, there has been little theoretical consensus on how the governing relationship between distance and trade flows holds nowadays. In this paper, I seek to empirically study whether the complicated response of trade to distance can be clarified by the hub-and-spoke structure of contemporary international freight distribution systems.

The hub-and-spoke network structure has imposed itself in countless international freight distribution and logistics systems owing to its efficiency. From the broader perspective of entire economic systems, it is also credited for the exponential acceleration of economic interaction at the global scale (Knowles 2006, Hummels 2007). A large stream of trade flows are now handled via transshipment at hub ports where efficient landside and seaside forwarding is enabled (Knowles 2006, Hesse 2013). Since the higher transport density of inter-hub trunk lines results in more intensive use of port facilities, containers and shipping services, the unit shipping cost declines as scale economies or density economies arise (Mori and Nishikimi 2002, Mori 2012, Xu and Itoh 2017).

Knowles (2006) argued that time- or cost-space convergence is not monotonic, but rather uneven along shipping routes owing to the uneven spatial quality of intermediate hub ports. The operation of hub ports enables expedited high-volume shipping with very inexpensive cost and less distance friction. For example, Mori and Nishikimi (2002) observed that, Singapore being a hub port, the effective speed of freight shipping to Japan is twice that to Jakarta, Indonesia, despite their equal distance. This not only suggests that physical Euclidean distance may be a simplistic measure of functional and economic separation (Tiller and Thill 2015), but also that the distance friction may depend on the specific properties of spatial interactions (Eldridge and Jones 1991). However, previous analyses have only studied aggregated trade flow patterns between countries, while glossing over the details of the trade logistic process that would have revealed the structuring role of ports and the deep complexity of the effect of distance friction on trade flows (Hummels and Skiba 2002). Accordingly, the inverse relationship between distance and trade flows should be revisited in the light of the adaptations of international logistics operations to accommodate hub-and-spoke network structures.

In this paper, I examine the extent to which the effect of the distance friction on spatial trade flows is tempered by the hub-and-spoke configuration. As a new explanation for the distance puzzle, this paper revisits the customary relationship between distance and trade flows by studying different route patterns of international trade flows. Specifically, I focus on tracing the differential collapse of cost-space in international trade back to the hub-and-spoke structure of the distribution system. Does a simple physical distance sufficiently explain the functional separation between places? If not, how does the effect of the geographical separation vary across shipping routes? Does the modern hub-and-spoke system ease distance friction and does it facilitate spatial trade flows? If so, how does the hub-and-spoke configuration along trade routes affect routing patterns of trade shipments?

To address these questions, I examine if and how the cost of trade shipments differs with respect to the trade logistic process associated with the transshipment behaviors and hub-and-spoke configuration set along the trade routes. I especially consider how transshipment and hub-and-spoke configuration constitute the generalized cost of shipping and affect decisions of shipping parties on the route choice for long-distance commerce. My hypothesis is that commerce benefits from the hub-and-spoke shipping economies by taking an intermediate hub port where shipping lines are diverse and port facilities are densely provided. Hence, I propose that hub-and-spoke shipping economies can reduce total freight costs and ease the friction of distance in commerce.

On the basis of micro-level footprints of container cargo shipments between Europe and the U.S., I track how freight shipping routes are differentiated, from the shipment source, to intermediate ports, and then to the U.S. port of entry. Micro-level shipping trajectories allow to identify the sequence of ports that each shipment traverses, which is taken as a proxy of the trade route to examine routing patterns. I set up a discrete choice model to examine route choice patterns with respect to whether shipments are transshipped and how the hub-and-spoke configuration is set along the route. I demonstrate that the generalized cost of shipping is diminished when they are processed through a route that exhibits characteristics of the hub-and-spoke system, namely being processed through ports that are larger and have more diverse shipping lines. Thus, long-distance commerce is not solely governed by the distance between points of origin and destination but it is also strongly influenced by the hub-and-spoke configuration of the shipping system and by nodal characteristics of the transshipment points.

I first review two strands of the literature pertaining to this research. Then I propose that the hub-and-spoke shipping economies and transshipment are important elements in routing commercial flows and that the hub-and-spoke configuration can discount trade shipping costs and distance friction. The next section provides the modeling strategy, followed by results of the analysis, and finally a discussion of the implications and conclusions.

2.2. Theoretical Underpinnings

Two strands of literature intersect to define the background of the research in this paper: 1) the distance puzzle in international trade and 2) the hub-and-spoke shipping economies. In this section, I review the theoretical background of each strand and synthesize it to draw my hypothesis that the hub-and-spoke freight distribution system weakens the distance friction on trade flows.

2.2.1. The Distance Puzzle: Has the Distance Friction Effect Declined in International Trade?

The inverse relationship between distance and trade flows has repeatedly been confirmed empirically using the framework of the gravity model (e.g., Bergstrand 1985, Deardorff 1998). Since the distance friction accounts for the largest part of the transportation cost, country-to-country crow-fly distance has often been used as a proxy for the transport cost to predict patterns of international trade flow (e.g., Bergstrand 1985, Buch *et al.* 2004, Coe *et al.* 2007). Distance has also been presented as a strong impedance in economic development and in accessibility to foreign markets in international trade studies (Blainey 1966, Behrens *et al.* 2006, Redding and Sturm 2008, Fratianni and Marchionne 2012, Robertson and Robitaille 2017).

On the other hand, ever since Tobler's (1970) introduction of the first law of geography, the absolute power of distance in spatial organization has been repeatedly called into question. Like the above-mentioned economic studies, the absolute distance perspective postulated a fixed regularity between physical distance and spatial flows; it dissociated the physical distance from socioeconomic processes (Thill 2011). Even though the inverse relationship is observed to hold in general, it has been found in various spatial relationships, such as transportation, commerce, commuting and migration, that the effect of distance is in fact not uniform and fixed, but rather contextual to relational properties of origins and destinations (Forer 1978, Gatrell 1983, Tiller and Thill 2015). Since the cost of moving goods over space has declined remarkably with the upgrading in the transportation system (Glaeser and Kohlhase 2004, Knowles 2006, Hummels 2007), it is expected that the inverse trade-to-distance relationship would become weaker as economic globalization proceeds. A number of studies have presented evidence in support of this view (e.g., Coe *et al.* 2002, Bleaney and Neaves 2013, Lendle *et al.* 2016). However, numerous country-level gravity modeling studies have presented opposite empirical evidence that the distance friction has remained robust and, sometimes, even gained strength. The latter conclusion, known as the “distance puzzle”, was reached by Disdier and Head (2008) in their meta-analysis of over one hundred studies in international bilateral trade.

More recently, a number of studies have sought to establish that trends in distance friction may vary with the context. In this respect, the trade of 25% of industries has become more sensitive to distance, and cross-border movement of differentiated goods is found to have higher distance friction than that of homogenous goods (Berthelon and Freund 2008). Between 1962 and 2000, more countries are found to selectively increase trade with countries at short distance, rather than with countries on long distance (Carrère and Schiff 2005). Head and Mayer (2013) explained that the distance friction still strongly matters, but in different ways, since other ‘dark’ distance factors, such as borders, cultural difference, information friction, colonial legacies, and long-run impacts of conflicts remain effective barriers to spatial economic interactions.

2.2.2. Hub-and-Spoke Distribution System and Economies of Scale

The hub port is a special node in the international logistics system that expedites high-volume flows and mediates inter-hub transportation links to local ports and other hubs (O’Kelly 1998). It also has a high level of throughput, site advantages and network accessibility in the logistic network that enable to process high volumes of freight from local feeder ports. Even though freight shipping through hubs takes circuitous routes with longer shipping distance than direct routes, inter-hub trunk line services using large container ships have facilitated large volumes of long-haul freight shipping with substantially reduced unit cost (O'Kelly 1998, Hummels and Skiba 2002, Knowles 2006). For this reason, the effective use of hub-and-spoke shipping economies has been a major driver of economic globalization, together with containerization and intermodal freight systems (Hesse and Rodrigue 2004, Knowles 2006, Hummels 2007). The distinctive nodality of hubs is recognized in economic geography as an important feature that reinforces the industrial agglomeration in the vicinity of ports (e.g., Krugman 1993, Fujita and Mori 1996, 2005).

The formation of the hub-and-spoke distribution system stems from economies of scale (O'Kelly and Bryan 1998, Mori and Nishikimi 2002, Hummels 2007). When regional shipping lines connect through denser services to a particular port, this port's infrastructure facilities and services are shared and there is a higher possibility to pool shipments on line-haul container ships with larger capacity and to offer specialized shipping services for certain goods (Mori and Nishikimi 2002, Mori 2012). The efficient use of shipping services and facilities generates scale economies. Through the positive feedback effect, the operation of the hub-and-spoke system attenuates the friction of distance by expediting a large volume of long-distance trade more efficiently.

The process of hub formation challenges the premise of international trade studies that the distance friction has a uniform and fixed effect across trade routes. The rise of scale economies suggests that the friction of distance may vary across trade routes in relation to the magnitude of density economies and the quality of the hub-and-spoke shipping network. This is consistent with Knowles' (2006) notion that the spatial quality of intermediate hub ports, such as centrality and intermediacy (Fleming and Hayuth 1994), can generate differential collapse in space. For example, even though the transshipment at hub ports requires more time for cargo handling, when two shipping routes are equidistant, the cost of shipping via the hub-and-spoke network would be substantially cheaper than the direct route due to density economies (Mori and Nishikimi 2002). Xu and Itoh (2017) focused on freight shipping flows after Japan's Hansin earthquake in 1995 and found that local export shipping from Eastern Japan switched their transshipment hub from nearby Japanese ports to Busan, South Korea, despite extended feeder shipping routes. In this case, density economies have drawn concentration of freight shipping to a larger but farther hub port because of cheaper transportation cost than a smaller nearby Japanese hub. This implies that trade impedance can be relative to how the traded goods are transported and it matters to consider the differentiation of the distance effect across possible trade routes.

Unquestionably, international trade studies on the distance puzzle have used the country-to-country Euclidean distance as an approximation of geographic remoteness in the gravity equation. Transshipment, shipping behaviors and logistic processes embedded in places along shipping routes have been sidelined in these studies (Hummels and Skiba 2002, Guerrero *et al.* 2016). Physical distance may not single-handedly determine the geographic patterns of international freight shipping since organizational proximity, like supply chain integration at ports, is instrumental in shaping patterns of logistic flows between places (Hall and Jacobs 2010). Hence, strategically located hub ports are instrumental in the efficient operation of international logistic systems as the spatial qualities of centrality and intermediacy of hubs determine the magnitude of distance friction (Knowles 2006).

2.2.3. Synthesis and Hypotheses

How does distance still matter in bilateral international trade? If the hub-and-spoke configuration of shipping systems has contributed to economic globalization, does distance friction decline when shipping takes routes through hub ports? How can I address the inverse relationship between distance and bilateral trade flows in consideration of how spatial interaction takes place? How does the improved efficiency on a hub-and-spoke configuration generate differential collapse in international trade? One of the possible ways to answer these questions is by examining the characteristics of trade flows processed through the transshipment and hub-and-spoke configuration of the shipping routes. This entails the measurement of the contribution of the hub-and-spoke configuration in the process of expediting freight shipments by reducing the friction of distance.

In order to substantiate the distance convergence and settle the distance puzzle, I adopt a discrete choice modeling framework to empirically compare routing patterns of freight shipments differentiated by their hub-and-spoke configurations and transshipment operations. Unlike the main strand of international trade literature that ignores the point-to-point shipping logistic process, this micro-level approach sheds new light on the spatial interactions embedded in the global trade landscape via the hub-and-spoke shipping configurations. The choice patterns between differentiated trade shipping routes will extend the understanding of the role of the hub-and-spoke distribution system in shaping the warped space in the global freight shipping system.

2.3. Data and Variables

2.3.1. Data

The freight route choice model is estimated on micro-level data of containerized shipping from Europe to the U.S., sourced from Port Import Export Recording Service (PIERS), a unit of IHS Markit. PIERS provides rich information on each shipment (bill of lading). Internal and external consistency checks were applied through manual and automated processes based on artificial intelligence to produce a dataset ready for use in research. Based on the geocoded spatial information of each shipping record, the shipping route can be reduced to a path with four nodes and three links (Figure 2-1). These nodes include 1) the source locality (O), 2) the first port of export (P1, first port, hereafter), 3) the last port of export (P2, final port, hereafter) and 4) the U.S. port of entry (PUS) (Figure 2-1). Basically, the last foreign ports of export in the PIERS are taken as P2. For P1, I take the so-called "pre-carrier[1]" city name in the PIERS dataset provided this city operates a port handling cargo vessels. If a shipment is not routed through a feeder port to the last port of export (P2), the last port of export is taken as P1. In the latter case, shipment is either directly forwarded to a U.S. port of entry (P2 = P1 to maintain the completeness of the data) or it is transshipped between the coasts of Europe and the U.S. port of entry, at a port labeled P2.

Depending on the locations of the four nodal points of a trajectory, three spatial scenarios can be differentiated (Figure 2-1): 1) direct routes, 2) West Atlantic transshipment routes (WTS routes) and 3) East Atlantic transshipment routes (ETS routes). On a direct route, shipment transits through a single port (final port) before entering the

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[1] The pre-carrier location indicates where the shipping line takes legal custody of the shipment.

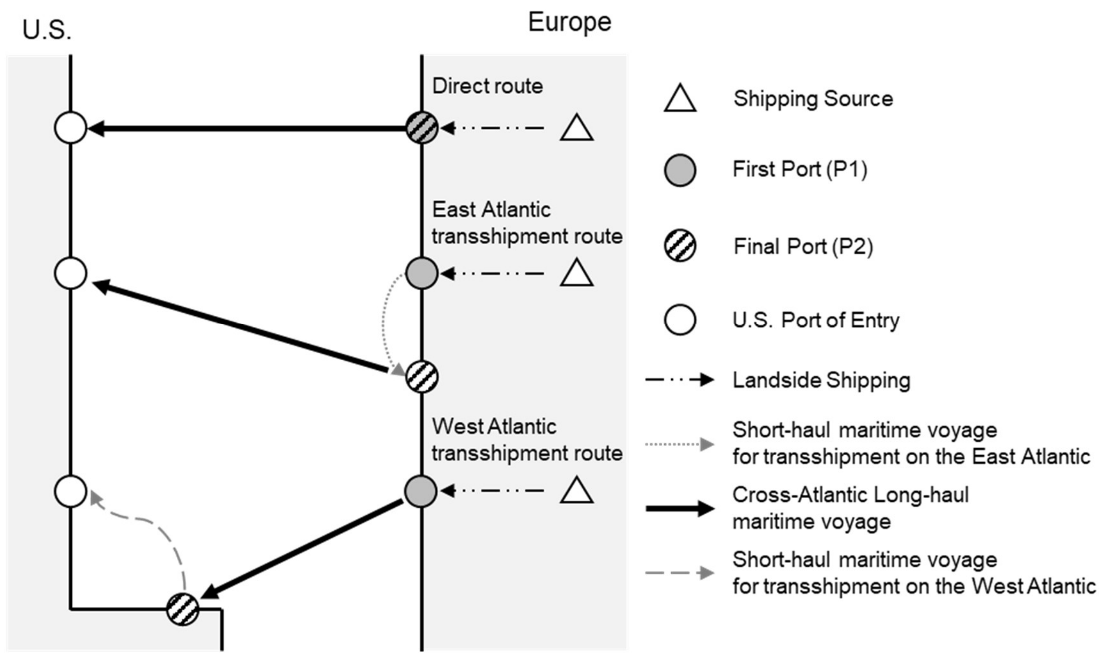


Figure 2-1 Direct and transshipment routes and forwarding and final ports

U.S. (P1 = P2). For routes with transshipment (hereafter, referred to as TS routes), I discern two cases in the analysis: transshipment on the East Atlantic (final ports in the Europe/Asia/North Africa) and on the West Atlantic (final ports in the Americas and in the Caribbean Sea, but not U.S.). When P1 and P2 are different (transshipment occurs), if both P1 and P2 are located in the East Atlantic, the transshipment is considered made before the long-haul trans-Atlantic voyage. Thus, the P1-P2 shipping segment is a short-haul maritime voyage on a feeder service, and the P2-PUS shipping segment is a line-haul trans-Atlantic voyage. If P2 is located in the West Atlantic, the transshipment is made after the line-haul trans-Atlantic voyage. In other words, the P1-P2 shipping segment is a line-haul trans-Atlantic voyage, and the P2-PUS shipping segment is a short-haul maritime voyage to the final destination after transshipment. Since the logistic sequences of maritime shipping are different in these two cases, I consider that their logistic process also would be very different and that it is important to identify which maritime segment (P1-P2 or P2-

PUS) is a line-haul trans-Atlantic voyage. This allows me to identify a triplet of maritime shipping distances for each shipment: 1) inter-port short-haul voyage distance on the East Atlantic, 2) line-haul trans-Atlantic shipping distance, 3) inter-port short-haul distance on the West Atlantic. When transshipment occurs on the East Atlantic, the short-haul distance on the West Atlantic is zero, and *vice versa*.

In this research, I use the containerized export shipping records from Europe to the U.S. in October 2006. Of 106,602 bills of lading of containerized cargo, a small number follow an infrequent route where the first and final ports have extremely small throughputs. Since my focus is of the general patterns of shipment routing between Europe and the U.S., these shipment cases depict idiosyncratic circumstances and can be regarded as outliers for this study. Accordingly, I use the following steps to filter out these bills of lading. I first exclude shipments whose line-haul voyage started at an extremely small port. Specifically, this happens when the line-haul voyage started at a port that is out of the 99.99th percentile by port throughput. Also, I only retain shipments whose first and final ports are identified to process more than 10 shipments in my initial data dataset of 106,602 bills of lading. As a result, the dataset is reduced to 97,454 bills of lading, from 12,367 source localities, 79 first ports of export (P1), 27 final ports (P2) and to 31 U.S. ports of entry (PUS). The total volume of shipping is 180,997.1 TEUs.

2.3.2. Measurement of shipping distances

Given the specificities of the bill of lading dataset, I start by explaining how trajectories of shipment records are traced in the dataset and how shipping distances are measured for each record. As a principle, I use the sequence of ports that a shipment traverses as a proxy for its shipping route. As previously mentioned, this is constrained by having only the four nodal points along the shipping routes across land and water (O, P1, P2 and PUS) in the dataset. Also, because the address of the U.S. consignee is often not indicative of the physical destination of the shipment, the U.S. port of entry is the last point that can be traced to a bill of lading in the dataset. For these reasons, I consider that a shipper chooses the sequence of a port pair (P1 and P2) with given points of a shipping source and U.S. port of entry (O and PUS).

Considering the limitations of the trajectory information, the geographical separation between shipping source, first and final ports and U.S. port of entry is approximated by the shortest-path distance on the road network and maritime voyage network. I measure the shortest-path distances between the shipping source and first port on the road network from CIESIN-ITOS (2013), and the distance between ports on the maritime voyage network from Oak Ridge National Laboratory (2000) for all routing alternatives of each shipment case.

2.3.3. Measurement of the hub-and-spoke configurations of shipping routes

To address how the hub-and-spoke shipping economies affect individual route choices for freight shipments and ultimately the emergence of a system of container flows on the aggregate, I consider three pathways and associated variables that may lead hub-and-spoke shipping economies to materialize, namely scale economies, ports' diversity in shipping line connections (Figure 2-2), and intermediacy of nodes on the shipping route. I capture these three configurations by measuring port-specific nodal characteristics identified in the inter-port maritime shipping network.

First, hub-and-spoke shipping economies arise with the scale of the ports (Figure 2-2-a). When a port is used heavily and its total throughput increases, the efficient use of

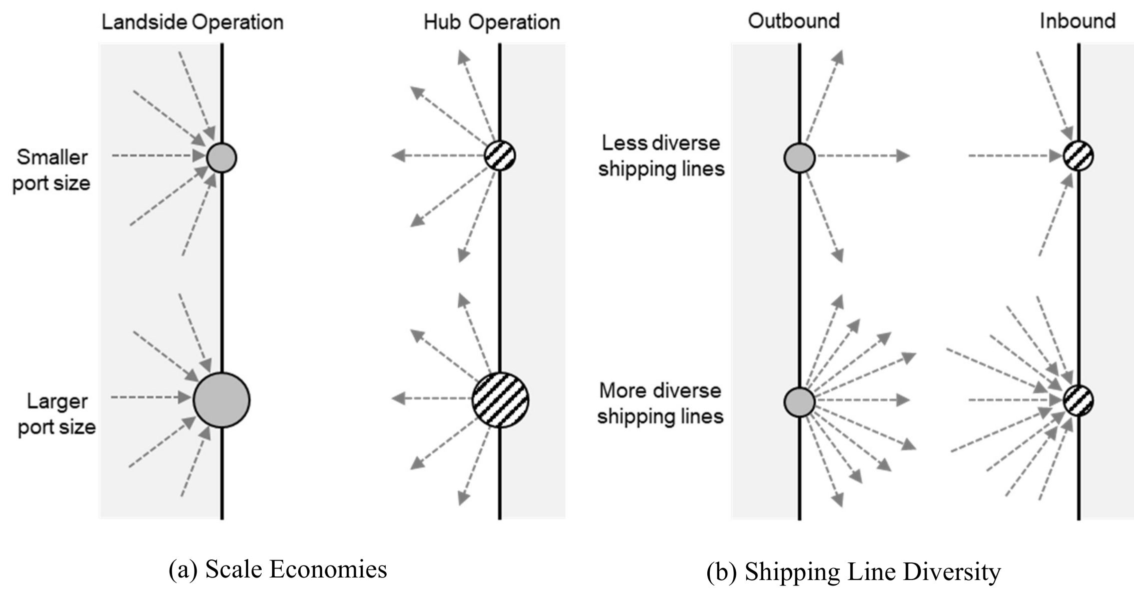


Figure 2-2 Illustration of the hub-and-spoke shipping economies: Scale economies and diversity effects

shipping services and port facilities can generate scale economies and decrease the unit cost of inter-port freight shipping. Scale economies that arise at the port can effectively be approximated by some measurement of the size of freight traffic at the port. A port can have both landside and hub operations, which need to be measured separately. The scale of landside operations (SLO) of a port can be approximated by its total landside inbound freight volume. Thus, I use the amount of freight transferred from the hinterland (land) to the maritime side. For measuring the scale of hub operations (SHO) of a port, I use the total maritime outbound freight volume shipped to U.S. ports of entry. This encompasses all the freight received from other first ports and from the port's hinterland that is shipped to U.S. ports of entry.

Second, hub-and-spoke shipping economies emerge when a port provides diverse inter-port connections between feeder and inter-hub shipping lines. If a shipping party dispatches shipment to multiple destinations, it would prefer sending them through ports providing diverse outgoing shipping lines, where they can flexibly change shipment schedules to diverse destinations and send them efficiently. The agglomeration of diverse shipping lines can make the transshipment process more fluid and smoother and ease the friction of freight flows because of enhanced connectivity of the shipping lines. I use the Shannon entropy index to quantify how diverse the shipping line services at a port are:

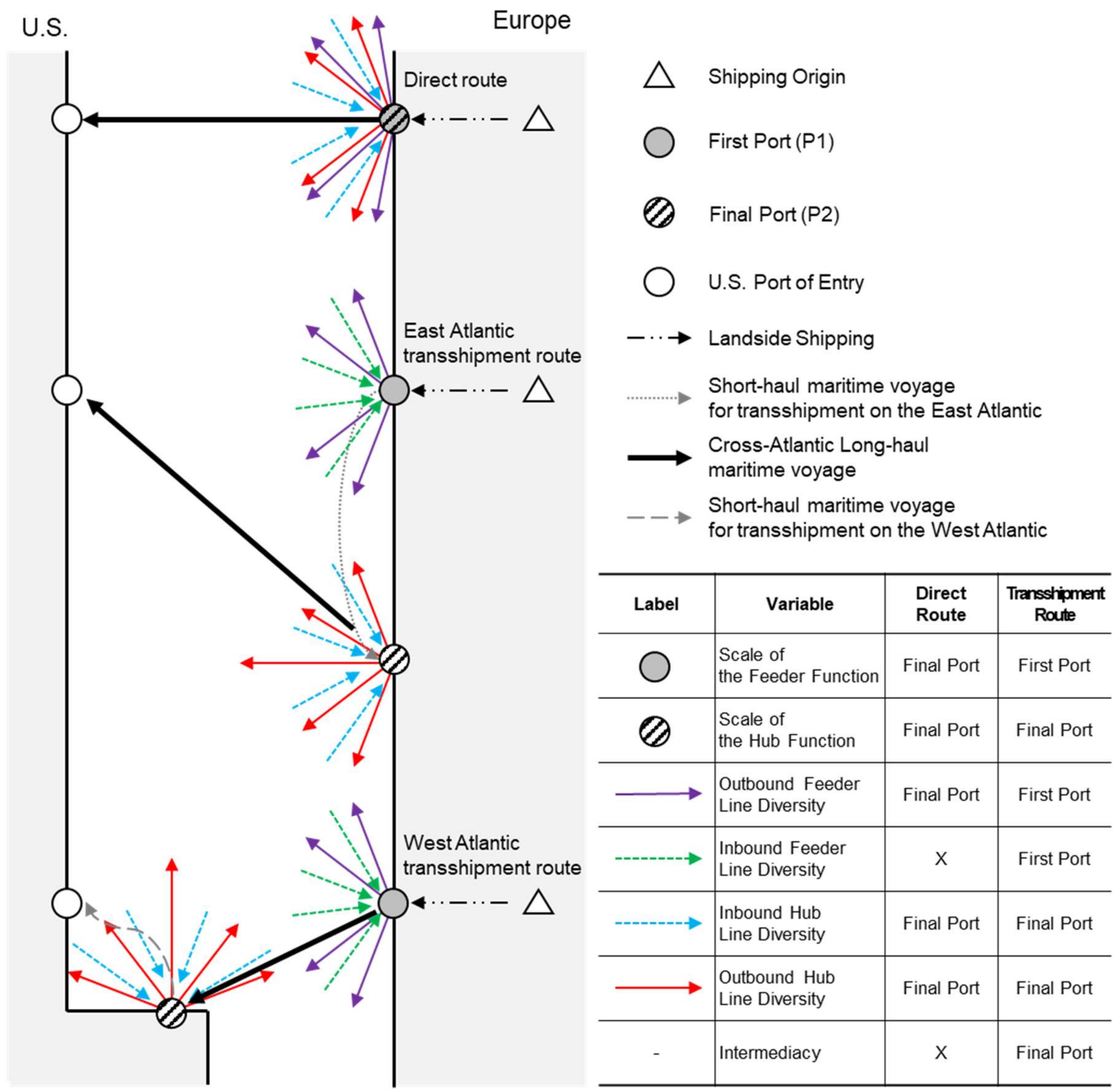
$$H_k = -\sum_l p_{kl} \ln p_{kl} \tag{2-1}$$

where H_k is the degree of diversity in the shipping line service of port k, l is a port that is connected to port k through some shipping services and p_{kl} is the proportion of freight shipment volume between l and k to the total throughput of port k. A greater value on the Shannon index indicates more diversity in shipping lines.

Like for the scale variables, shipping line diversity is measured for both the landside and hub functions (Figure 2-2-b). For the former, the Shannon index is measured on outbound maritime feeder lines to other ports (hereafter, outbound feeder line diversity) to represent how diverse final ports can be reached through the port. For the hub function, two aspects of shipping line diversity need to be considered, namely connectivity from feeder ports and connectivity to U.S. ports of entry. The Shannon index is measured on inbound maritime shipping lines from other ports (inbound hub line diversity) to indicate how diverse feeder lines are collected for transshipment at the port for the voyage to the final destination ports; it is also measured on outbound maritime shipping lines to U.S. ports of entry (outbound hub line diversity) to represent how diverse U.S. ports can be reached through the port.

Third, following Fleming and Hayuth's (1994) notion of intermediacy as the spatial quality of the hub location, I measure how the final port is located *en route* or "on the way" between origin and destination. They argue that a place acquires more geographical advantage to be a hub location when it has higher intermediacy by being placed in the middle of direct shipping lines between origin and destination rather than when it is placed far. If the place is an overlapping point of the multiple direct shipping lines, the place can be a way-stop point where shipments can rest and work as a terminal where endpoints of multiple shipping lines can meet. For each route, I measure the intermediacy by the ratio of the direct maritime shipping distance between the shipment's origin and destination and the route's total maritime shipping distance. If the ratio is closer to 1, the route's total shipping distance is more approximated to the direct route's, indicating that the final port is geographically located less away from the "on the way" point of the direct shipping route. If the value is closer to zero, the route's total shipping distance is much longer than the direct route's, meaning that the final port is located away from the "on the way" point.

As presented in Figure 2-3, on a direct route, hub-and-spoke configuration variables (SLO, SHO, outbound feeder line diversity, inbound hub line diversity, outbound hub line diversity and intermediacy) are all measured on the final port. For the routes with transshipment, I consider that feeder and hub functions are carried out by the first and final port, respectively. Hence, the SLO and outbound feeder line diversity are measured on the first port while the SHO, inbound and outbound hub line diversity are measured on the final port. I include diversity in inbound shipping lines at the first port (inbound feeder line diversity) to consider how inbound shipping lines can produce a spillover effect on the operation of the first port. Descriptive statistics of the shipment- and route-specific variables used in the study are reported in Table 2-1.



Label	Variable	Direct Route	Transshipment Route
	Scale of the Feeder Function	Final Port	First Port
	Scale of the Hub Function	Final Port	Final Port
	Outbound Feeder Line Diversity	Final Port	First Port
	Inbound Feeder Line Diversity	X	First Port
	Inbound Hub Line Diversity	Final Port	Final Port
	Outbound Hub Line Diversity	Final Port	Final Port
-	Intermediacy	X	Final Port

Figure 2-3 Hub-and-spoke configuration variables measured on forwarding and final ports

Table 2-1 Descriptive statistics

Variable	Unit	Mean	Standard Deviation	Min	Max
Landside Distance, d_{ij} (Source – First Port)	100 km	15.662	8.83	0.076	66.760
Short-haul Maritime Distance in the East Atlantic, $m_{E,ij}$	100 km	16.479	16.34	0	152.741
Long-haul Maritime Distance, $m_{L,j}$	100 km	81.865	27.356	53.331	203.698
Short-haul Maritime Distance in the West Atlantic, $m_{A,ij}$	100 km	2.851	10.783	0	121
Transshipment	Dummy variable (1: Yes, 0: No)	0.941	0.236	0	1
Transshipment in the East Atlantic	Dummy variable (1: Yes, 0: No)	0.845	0.362	0	1
Transshipment in the West Atlantic	Dummy variable (1: Yes, 0: No)	0.096	0.295	0	1
Crossing the Panama Canal	Dummy variable (1: Yes, 0: No)	0.114	0.318	0	1
ln(Scale of Landside Operations) (Landside Inbound Freight)	TEUs, Log Scale	7.134	1.69	4.061	10.289
ln(Scale of Hub Operations) (Seaside Outbound Freight to the U.S.)	TEUs, Log Scale	8.891	1.366	3.689	10.612
Outbound Feeder Line Diversity	Shannon Index	1.331	0.53	0	2.433
Inbound Feeder Line Diversity	Shannon Index	0.784	1.084	0	3
Inbound Hub Line Diversity	Shannon Index	2.456	0.64	0.623	3.224
Outbound Hub Line Diversity	Shannon Index	1.737	0.441	0	2.383
Intermediacy	N/A	0.81	0.231	0	1
Shipper Size	1,000 Twenty-foot Equivalent Units	0.098	0.442	0.00001	8.737
Unit Value	1,000 USD / kg	0.008	0.042	0	11.263
Shipment Volume	Twenty-foot Equivalent Units	1.834	3.622	0.01	391.85

Notes: Sample includes 3,736,211 observations (97,454 bills of lading)

2.4. Modeling Strategy

2.4.1. Discrete Choice Model of Port Pairs Aligned with Shipping Routes

To study how hub-and-spoke shipping economies arise along shipping routes and how they help alleviate the deterrence of distance in intercontinental shipping flows, I adopt a discrete choice analysis framework (McFadden 1978a, Train 2009, Ortúzar and Willumsen 2011). Specifically, this approach enables us to express the selection of shipping routes connecting certain ports as a function of the properties of ports and of the arrangement of ports and shipping segments in the overall maritime shipping systems. The discrete choice model has been widely adopted in port choice studies (e.g., Malchow and Kanafani 2001, 2004, Steven and Corsi 2012, Kashiha *et al.* 2016) to find how characteristics of shipments and ports affect freight mobility through ports. Here the problem under study is that of shipping route choices, specifically the selection of the pair of ports that form a route. The model identifies whether a shipping party prefers to ship through a route where more hub-and-spoke shipping economies emerge.

I define the deterministic part of the utility V_{ij} of shipment i choosing route j by the distance friction, and a series of shipment- and alternative-specific variables:

$$V_{ij} = V_{ij}(\boldsymbol{D}, \boldsymbol{X}_i, \boldsymbol{Z}_j) = u_{ij}(\boldsymbol{D}) + v_j(\boldsymbol{Z}_j) + w_{ij}(\boldsymbol{D}, \boldsymbol{X}_i) \tag{2-2}$$

where $\boldsymbol{D}$ denotes the covariates of landside and maritime distances, u_{ij} is a function of them, $\boldsymbol{X}_i$ is the shipment-specific covariates, $\boldsymbol{Z}_j$ denotes the alternative-specific covariates including characteristics of the route and of the pair of ports along the route, v_j is a function of these characteristics, and finally w_{ij} indicates a function of other shipment-specific controls and distance covariates. For identification of the shipment-specific effects, shipment-specific covariates interacted with distance terms are used in w_{ij}.

Here I first specify u_{ij} by the linear effects of four segments of landside and maritime shipping distances and transshipment:

$$u_{ij} = \gamma_d d_{ij} + \phi_E \times T_j \times m_{E,ij} + \phi_L m_{L,j} + \phi_A \times T_j \times m_{A,ij} + \alpha T_j \qquad (2\text{-}3)$$

where d_{ij} is the landside shipping distance between shipping source and first port (O–P1), $m_{E,ij}$ is the short-haul maritime distance on the East Atlantic (before the long-haul trans-Atlantic maritime voyage), $m_{L,j}$ is the long-haul trans-Atlantic maritime voyage distance, $m_{A,ij}$ is the short-haul maritime distance on the West Atlantic, T_j is a dummy variable indicating whether alternative j encompasses transshipment (P1 and P2 are different), γ and ϕ are the corresponding coefficients of distance friction effects, and α is a fixed effect of transshipment.

I should note how the three maritime distances are coded in consideration of the trans-Atlantic shipping records. The East Atlantic distance $m_{E,ij}$ is non-zero only when transshipment occurs on the East Atlantic (European/Asian/North African ports); similarly, the West Atlantic distance $m_{A,ij}$ is non-zero only when transshipment occurs on the West Atlantic (American (not U.S.)/Caribbean ports). Thus, for the direct shipment, only the long-haul trans-Atlantic voyage distance $m_{L,j}$ is positive, while $m_{E,ij}$ and $m_{A,ij}$ are zero. The transshipment dummy variable T_j is interacted with the two short-haul distances to indicate that there is short-haul distance friction only when transshipment occurs.

Then I specify the route-specific effects v_j associated with the hub-and-spoke configuration. Since each route is composed of a traversed port pair, these effects are operationalized through the port-specific nodal characteristics of the first and final ports. The route-specific effects v_j on route j are specified as follows:

$$v_j = \rho_f S_j^{land} + \rho_h S_j^{hub} \\ +\lambda_{in} \times T_j \times HI_{j,1} + \lambda_{out} HO_{j,1} + \zeta_{in} HI_{j,2} + \zeta_{out} HO_{j,2} + \pi \times T_j \times I_j \tag{2-4}$$

where S_j^{land} and S_j^{hub} are SLO and SHO, respectively, $HI_{j,1}$ and $HO_{j,1}$ is the inbound and outbound feeder line diversity, $HI_{j,2}$ and $HO_{j,2}$ are the inbound and outbound hub line diversity measures, respectively, and I_j is intermediacy of the final port on route j; ρ, λ, ζ and π denote the corresponding effects. For transshipment routes ($T_j = 1$), $HI_{j,1}$ and $HO_{j,1}$ are measured on the first port, carrying out feeder functions, and $HI_{j,2}$ and $HO_{j,2}$ are measured on the final port, carrying out hub functions. For direct routes ($T_j = 0$), $HO_{j,1}$, $HI_{j,2}$ and $HO_{j,2}$ are measured on the final port. Inbound feeder line diversity $HI_{j,1}$ and intermediacy I_j are considered only for transshipment routes, transshipment dummy T_j enters the utility function multiplicatively so that its effects are muted for direct routes. Since the shipment-specific characteristics do not vary across the route alternatives within each shipment, their effect cannot be directly estimated by the conditional logit model. To circumvent this issue, I instead interact them with each of the four distance terms to control the shipment-specific effects. The shipment-specific control part w_{ij} in Equation 2-2 is defined as follows:

$$w_{ij} = d_{ij} \times \boldsymbol{X}_i \times \boldsymbol{\beta}_d + m_{E,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_E \\ +m_{L,j} \times \boldsymbol{X}_i \times \boldsymbol{\beta}_L + m_{A,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_A \tag{2-5}$$

where $\boldsymbol{\beta}$ is a vector of coefficients of the shipment-specific covariates $\boldsymbol{X}_i$. The dummy variable for transshipment T_j is added to indicate that the shipment-specific effects interacted with the short-haul distance, $m_{E,ij}$ or $m_{A,ij}$, exist only when taking a route encompassing transshipment. I include the shipment volume (TEUs), shipper size by total volume (TEUs), unit value of the shipment ($ per kg), and a dummy variable indicating whether a shipment crosses the Panama Canal as the shipment-specific covariates $\boldsymbol{X}_i$. Plugging Equations 2-3, 2-4 and 2-5 into Equation 2-2, the model becomes:

$$\begin{aligned} V_{ij} = {} & \gamma_d d_{ij} + \phi_E \times T_j \times m_{E,ij} + \phi_L m_{L,j} + \phi_A \times T_j \times m_{A,ij} \\ & +\alpha T_j + \rho_f S_j^{land} + \rho_h S_j^{hub} \\ & +\lambda_{in} \times T_j \times HI_{j,1} + \lambda_{out} HO_{j,1} + \zeta_{in} HI_{j,2} + \zeta_{out} HO_{j,2} \\ & +\pi \times T_j \times I_j \\ & +d_{ij} \times \boldsymbol{X}_i \times \boldsymbol{\beta}_d + m_{E,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_E \\ & \quad +m_{L,j} \times \boldsymbol{X}_i \times \boldsymbol{\beta}_L + m_{A,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_A. \end{aligned} \tag{2-6}$$

If the hub-and-spoke shipping economies arise with SLO, SHO and shipping line diversity, then the coefficients of the scales and shipping line diversity indices, ρ and ζ, would take a positive sign. Also, if a final port's intermediacy is advantageous, the coefficient of intermediacy π is expected to display a positive sign.

Additionally, I consider if the hub-and-spoke shipping economies and distance friction arise differently along transshipment and direct routes. It should be noted that while the feeder and hub functions are physically divided across first and final ports along transshipment routes, all logistic functions are co-located and integrated at the final port along the direct route. This difference in the logistic arrangement may have the hub-and-spoke shipping economies arise in different ways for transshipment and direct routes, and it is worth checking if the effects of the hub-and-spoke configuration and distance friction are different.

I examine if the hub-and-spoke shipping economies and distance friction arise differently along the ETS and WTS routes. As far as trans-Atlantic trade shipments are concerned, it is important to acknowledge that the hub function of the West Atlantic ports is different from that of the East Atlantic as their proximity to the U.S. ports are a distinctive feature. The East Atlantic ports mainly take the role of providing direct long-haul shipping lines to U.S. ports while West Atlantic ports redistribute the received long-haul shipments from Europe to different U.S. ports. It is possible that the hub-and-spoke shipping economies differ by the port location and resulting hub function. Since the model in Equation 2-6 cannot confirm if and how the effects of distance friction and hub-and-spoke configuration are different by transshipment, I expand Equation 2-6 by adding distance, hub-and-spoke configuration terms and shipment-specific covariates interacted with the transshipment dummy T_j as follows:

$$
\begin{aligned}
V_{ij} &= (\gamma_d + \ddot{\gamma}_d T_j) d_{ij} + \phi_E \times T_j \times m_{E,ij} + (\phi_L + \ddot{\phi}_L T_j) m_{L,j} \\
&+ \phi_A \times T_j \times m_{A,ij} + \alpha T_j \\
&+ (\rho_f + \ddot{\rho}_f T_j) S_j^{land} + (\rho_h + \ddot{\rho}_h T_j) S_j^{hub} \\
&+ \lambda_{in} \times T_j \times HI_{j,1} + (\lambda_{out} + \ddot{\lambda}_{out} T_j) HO_{j,1} \\
&+ (\zeta_{in} + \ddot{\zeta}_{in} T_j) HI_{j,2} + (\zeta_{out} + \ddot{\zeta}_{out} T_j) HO_{j,2} + \pi \times T_j \times I_j \\
&+ d_{ij} \times \boldsymbol{X}_i \times (\boldsymbol{\beta}_d + T_j \times \ddot{\boldsymbol{\beta}}_d) + m_{E,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_E \\
&+ m_{L,j} \times \boldsymbol{X}_i \times (\boldsymbol{\beta}_L + T_j \times \ddot{\boldsymbol{\beta}}_L) + m_{A,ij} \times T_j \times \boldsymbol{X}_i \times \boldsymbol{\beta}_A
\end{aligned}
\qquad (2\text{-}7)
$$

where $\ddot{(\cdot)}$ indicates the additional effect of the corresponding variable by transshipment. The main parameters of interest are the additional distance effects, $\ddot{\gamma}_d$ and $\ddot{\phi}_L$, and additional ports' scale and diversity effects, $\ddot{\rho}$, $\ddot{\lambda}$ and $\ddot{\zeta}$. If these coefficients are found positive or negative, shipping would draw higher or lower benefits, respectively, from the hub-and-spoke shipping economies with transshipment.

2.4.2. Estimation Issues

In approaching the choice problem of freight routing, I need to consider the implications of the assumption of independence of irrelevant alternatives (IIA), which is a core feature of the conditional logit model. The IIA property is indeed not likely to hold in the context of this research, which would affect the consistency of parameter estimates. Instead, I use the mixed logit formulation which is not restricted by the IIA property because it depends on all alternatives in the dataset, not just the two alternatives compared (Train 2009). The mixed logit model also allows for random taste variation by estimating individual-level coefficients on selected variables across individual cases. Specifically, since landside and long-haul maritime shipping distances and transshipment account for the shipping process, I impose random taste variation on their coefficients γ_d, ϕ_L and α_0 in Equation 11 to consider possible variation in their effects across shipments.

Second, choice sets must be purposefully designed. I generate choice sets that differ across individual shipments for computational efficiency in estimation. For my dataset, there are 589 observed pairs of first and final ports. They form the universal choice set for the shipments. However, a shipping party cannot realistically consider all the alternatives in the universal choice set, especially alternatives whose first port is very far away from the shipment source. For example, a shipper in Dublin, Ireland, would not plausibly truck inland through Gioia Tauro, Italy. Also, when using the universal choice set, the estimation on 57,400,406 cases (97,454 shipments × 589 alternatives) would be computationally very expensive.

Following Thill (1992), instead of using the universal choice set for estimation purposes, I build varying choice sets that consist of the geographically feasible alternatives for each shipment. Each choice set is constructed in a way that the size of the dataset is reduced but parameters can be estimated consistently. First, for each shipment, starting from the universal choice set, I construct a 'feasible' choice set by dropping alternatives whose landside shipping distance is over 1.5 times the largest actual landside shipping distance of any shipment sourced from the same country. For example, for a shipment from Madrid, Spain, if 500km is the longest shipping distance recorded for any Spanish shipment, I only consider as feasible the alternatives whose inland shipping distance is less than 750km. In addition, taking McFadden's (1978b) approach, the final choice set is formed as the union of the chosen alternative of the shipment and a 10% random sample of non-chosen alternatives in the feasible choice set. This process reduces the size of each shipment's choice set from 589 to the range of 3 to 47 and that of the dataset from 57,400,406 to 3,736,211.

2.5. Empirical Results

2.5.1. Baseline Results

I first estimate a mixed logit model as defined in Equation 2-6 to examine the effect of distance and of the hub-and-spoke configuration on the routing of shipments (Table 2-2). The model includes landside, long-haul trans-Atlantic and short-haul distances, a dummy variable for whether the route involves transshipment, port SLO and SHO, shipping line diversity measures, and a set of shipment-specific variables interacted with the four distance terms to control the shipment-specific effects. As a robustness check on the estimation results, I alternatively include and exclude these sets of variables and observe how coefficient values change: 1) a set of distance variables and a dummy variable for transshipment are included (column 1); 2) shipment-specific control variables interacted with distances are added to the first specification (column 2); 3) only hub-and-spoke configuration variables are added to the first specification (column 3); 4) both sets of variables are added (column 4). Since the signs and magnitudes of the coefficients are rather stable across model specifications, I can confirm that the estimation results are robust and do not exhibit omitted observation bias.

Table 2-2 Port pair choices and hub-and-spoke configuration: Main results of the mixed logit model under diverse specifications

		(1)	(2)	(3)	(4)
Distances	Landside Distance§	-0.83211***	-0.76659***	-0.86433***	-0.80539***
		(0.00637)	(0.00701)	(0.00724)	(0.00787)
	Long-haul Maritime Distance§	-0.08869***	-0.08401***	-0.06929***	-0.06786***
		(0.00143)	(0.00203)	(0.00200)	(0.00248)
	Short-haul Maritime Distance	-0.10710***	-0.10255***	-0.12011***	-0.11621***
	(East Atlantic)	(0.00157)	(0.00204)	(0.00240)	(0.00288)
	Short-haul Maritime Distance	-0.07933***	-0.08707***	-0.04821***	-0.03530***
	(West Atlantic)	(0.00163)	(0.00339)	(0.00215)	(0.00442)
Transshipment	Transshipment§	-4.75632***	-4.69092***	-4.51194***	-4.54276***
	(1: Yes, 0: No)	(0.04905)	(0.04837)	(0.23690)	(0.25019)
Alternative-specific Hub-and-spoke characteristics	ln(Scale of Landside Operations)			0.60778***	0.59964***
	(Landside Inbound Freight)			(0.01125)	(0.01127)
	ln(Scale of Hub Operations)			0.70100***	0.70239***
	(Seaside Outbound Freight to the U.S.)			(0.01307)	(0.01374)
	Outbound Feeder Line Diversity			0.18935***	0.19536***
	(First Port, Outbound Feeder Lines)			(0.02073)	(0.02074)
	Inbound Feeder Line Diversity			-0.83990***	-0.83851***
	(First Port, Inbound Feeder Lines)			(0.01980)	(0.01979)
	Inbound Hub Line Diversity			0.25769***	0.24588***
	(Last Port, Inbound Feeder Lines)			(0.02031)	(0.02077)
	Outbound Hub Line Diversity			-0.61032***	-0.59536***
	(Last Port, Outbound U.S. Lines)			(0.02977)	(0.02997)
	Intermediacy			1.78167***	1.81066***
	(Last Port)			(0.24007)	(0.25301)
Shipment-specific Controls (Interacted with distances)	Landside Distance		-0.66463***		-0.39851**
	× Unit Value		(0.12050)		(0.12324)
	Long-haul Maritime Distance		-0.68100***		-0.44328***
	× Unit Value		(0.11028)		(0.11049)
	Short-haul Maritime Distance		-0.72305***		-0.48270***
	(East Atlantic) × Unit Value		(0.11294)		(0.11467)
	Short-haul Maritime Distance		-0.84793***		-0.49299***
	(West Atlantic) × Unit Value		(0.12994)		(0.12920)
	Landside Distance		-0.01518***		-0.01646***
	× Shipping Volume		(0.00196)		(0.00211)
	Long-haul Maritime Distance		-0.00122**		-0.00145**
	× Shipping Volume		(0.00040)		(0.00046)
	Short-haul Maritime Distance		-0.00103*		-0.00099*
	(East Atlantic) × Shipping Volume		(0.00045)		(0.00048)
	Short-haul Maritime Distance		-0.00078*		-0.00089*
	(West Atlantic) × Shipping Volume		(0.00039)		(0.00045)
	Landside Distance		-0.41749***		-0.38545***
	× Shipper Size		(0.02866)		(0.03050)
	Long-haul Maritime Distance		0.00673**		0.00909**
	× Shipper Size		(0.00238)		(0.00333)
	Short-haul Maritime Distance		0.00213		0.01000
	(East Atlantic) × Shipper Size		(0.00456)		(0.00552)
	Short-haul Maritime Distance		0.00589**		0.00959**
	(West Atlantic) × Shipper Size		(0.00223)		(0.00315)
	Long-haul Maritime Distance		0.05610***		0.03096***
	× Panama-Crossing		(0.00447)		(0.00559)
	Short-haul Maritime Distance		0.02413***		0.01466***
	(East Atlantic) × Panama-Crossing		(0.00354)		(0.00404)
	Short-haul Maritime Distance		0.06550***		0.01554*
	(West Atlantic) × Panama-Crossing		(0.00491)		(0.00620)
	Log Likelihood	-49,773.776	-49,360.380	-42,458.867	-42,120.396
	Number of Cases	3,736,211	3,736,211	3,736,211	3,736,211

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; § Random coefficients; Standard errors in parentheses.

Consistently with the existing literature, the estimation results confirm the inverse relationship between distance and trade flow. All columns in Table 2-2 present that distance has a consistently negative effect on all the shipping flow segments between European sources and U.S. ports of entry. The magnitude of the distance effect varies across segments. Specifically, the friction of the landside distance is greatest, that of the East Atlantic short-haul and long-haul maritime distances follows, and that of the West Atlantic short-haul maritime distance is least. I find that the landside distance friction is more than ten times greater than the long-haul maritime shipping distance friction; this confirms that the freight rate of the landside shipping is much higher than that of maritime shipping. Column 4 presents that the odds of choosing a route decrease by 0.802 % ($e^{-0.80539/100} - 1 = -0.802\%$) with each additional kilometer of the landside shipping distance, while there is a marginal decrease of 0.068 % with the long-haul maritime shipping distance ($e^{-0.06786/100} - 1 = -0.068\%$). This implies that maritime shipping is far more efficient than landside shipping, which is in line with the fact that containerization and pooling of large volumes of shipments in containerships reduce the unit freight cost and facilitates the scale economies in maritime shipping.

I should note that the coefficient of the long-haul maritime shipping distance is lower than those of the East Atlantic short-haul maritime distance but higher than those of the West Atlantic short-haul maritime distance. This difference may be associated with the difference in the role of hubs on the East and West Atlantic, respectively; While an East Atlantic hub port gathers freights through short-haul feeder shipping lines and forward them through long-haul shipping lines, that on the West Atlantic receives bulk shipments delivered through the long-haul voyage and redistribute them to feeder lines to the U.S.

With many Caribbean ports on the West Atlantic taking the role of outshore ports that reduce the bottleneck of inbound traffic at U.S. ports of entry, the lower coefficient of the West Atlantic short-haul shipping distance demonstrates unique benefits of shipping through hub ports in the West Atlantic.

I also confirm that variables associated with the hub-and-spoke configuration have significant effects on shipping flow. First, the results indicate that a route is strongly preferred when the SLO and SHO of traversed ports are larger. Controlling for distance friction and shipment-specific effects, the SLO and SHO are strong predictors of the selection of a route. If the SLO on a route is 1% larger, this route sees its likelihood of being followed increased by 0.598 % ($e^{0.59964 \times \ln\ .01} - 1 = 0.598\%$). The impact of SHO is positive and of a greater magnitude than the SLO; if the SHO of a route has 1% larger, a shipper is 0.701 % ($e^{0.70239 \times \ln\ .01} - 1 = 0.701\%$) more likely to choose it over others. This shows that economies of scale are derived from the size of landside and hub operations, and the scales of both functions are a critical component of the hub-and-spoke shipping economies.

Along with the scale of operations of ports, their shipping line diversity is a strong driver of shipment routing, but the signs of their effects are mixed. Columns 3 and 4 of Table 2-2 shows positive effects of outbound feeder and inbound hub line diversity, indicating that hub-and-spoke shipping economies stem from a feeder's connectivity to diverse hubs and a hub's connectivity from diverse feeders. Specifically, column 4 reports that 0.1 unit of Shannon index of the outbound feeder or inbound hub line diversity of a route increases the odds of choosing this route by 1.973% ($e^{0.19536 * 0.1} - 1 = 1.973\%$) or 2.489% ($e^{0.24588 * 0.1} - 1 = 2.489\%$), respectively. This shows that diversity in the feeder-hub shipping lines is an important component of the hub-and-spoke configuration for reducing the friction of distance in freight shipping.

However, the shipping line diversity of ports does not always generate benefits conducive to shifting shipping flows. Our results show that the inbound feeder and outbound hub line diversities have a negative effect on the odds of choosing a route, unlike the outbound feeder and inbound hub shipping line diversities. This means that the diverse inbound feeder shipping lines at the first port may impede the feeder operation of transferring shipments to other ports by creating congestion between inbound and outbound maritime traffic. It is also notable that the shipping line diversity to U.S. ports is not a port feature that is effective at attracting shipping flows away from other routes as this may create congestion at the final port during the transshipment process. Thus, hub-and-spoke shipping economies on a route can be more effectively enhanced when the first port is dedicated to its landside operations and to feeder services to other ports, rather than a hub function that transfers maritime shipments to U.S. ports, and when the final port maintains a minimal number of shipping lines to U.S. ports.

The analysis also confirms that the intermediacy of the final port is a strong predictor of shipping route choice. The coefficients of intermediacy exhibit positive signs with statistical significance at 1% in columns 3 and 4, indicating that a route is strongly preferred when the final port is placed close to the direct route between origin and destination ports. Column 4 reports that 0.1 unit of the intermediacy index increases the odds of choosing a route by 19.849% ($e^{1.81066*0.1} - 1 = 19.849\%$). Thus, a shipper tends to prefer a route with higher intermediacy --whose final port is placed closer to the midway of the direct route between origin and destination ports, indicating that intermediacy is a locational advantage of a hub port.

Our baseline results point to important causal factors of the structuring of spatial trade flows. The nodal characteristics of ports associated with hub-and-spoke configurations are found to be significant factors in governing the behavior of spatial trade flows. Thus, the hub-and-spoke configuration should be important for patterns of spatial trade flows, beyond physical distance. In the existing international trade literature, it is standard to use the country-to-country crow-fly distance to represent the physical separation between points of origin and destination. My results show that the spatial relationship between origin and destination is not determined by the simple crow-fly distance between origin and destination, but by the length of shipping segments with different qualities and by the hub-and-spoke configuration along the route. Thus, using such a simple distance measure may not fully reveal the inverse relationship between distance and trade flow. There is evidence that additional "dark" distance factors significantly affect the spatial organization of trade flows beside the shipping distance, such as how freight is delivered in each stage in the trade logistic process from location to location, and the spatial qualities of hub ports traversed along the route.

2.5.2. Differential effects of distance and hub-and-spoke configuration

In order to examine whether the friction of distance and the effects of hub-and-spoke configuration manifest themselves differently when transshipment takes place or not and where this takes place along the supply chain, I estimate a model (Equation 2-7) that compares these effects along ETS and WTS routes vis-à-vis the direct route. Table 2-3 provides coefficients estimated that allow to identify the difference in the magnitude of the effects along the ETS or WTS routes against direct routes. While the baseline column presents the effects of the explanatory variables along the direct route, the ETS or WTS Specific columns identify additional effects along ETS or WTS routes against direct routes. Thus, the effects that a shipment receives along the ETS or WTS routes are indicated by the sum of the values in the baseline and ETS or WTS columns.

While the detailed results are reported in Table 2-3 for all the explanatory variables, we focus here on the target variables of hub-and-spoke configuration. The sign of their effects is summarized by type of routes (Table 2-4) and discussed hereafter. I first find that intermediacy of the final port is found to have a positive effect on shipping flow along both TS routes. The result presents a larger coefficient along the ETS routes, indicating that intermediacy has a greater effect than along WTS routes. However, I find a limited degree of consistency in the signs of the effects of other hub-and-spoke configuration variables across type of routes, but mostly variability across route types. The latter indicates that the hub-and-spoke shipping economies do not consistently arise with port scale and shipping line diversity. The main results are discussed below.

First, scale economies arise with SLO and SHO, except the SLO along direct routes. The results from Tables 2-2 and 2-3 present that there is a strong preference for a route with larger SLO and SHO, indicating that scale economies can generally ease the distance friction of freight shipping. However, SLO exhibits a negative sign along direct routes; a direct route with a larger SLO is found not to be preferred over other routes. This would be consistent with port congestion due to elevated throughput stemming from SLO, which may hinder direct shipping. Along direct routes, all the logistic processes taking place at the final port, delay of receiving shipments from the landside and transfer delays from land

Table 2-3 Differential effects of the distances and hub-and-spoke configuration on port pair choices

	Baseline (Direct)	East TS Specific	West TS Specific
Landside Distance§	-0.76715***	-0.11997***	-0.03636
	(0.00848)	(0.01084)	(0.02000)
Long-haul Maritime Distance§	-0.08080***	0.01913***	0.02932***
	(0.00293)	(0.00179)	(0.00672)
Short-haul Maritime Distance		-0.11441***	
(East Atlantic)		(0.00313)	
Short-haul Maritime Distance			-0.15671***
(West Atlantic)			(0.00851)
Transshipment§		-6.76186***	-4.12737***
(1: Yes, 0: No)		(0.39846)	(1.11273)
ln(Scale of Landside Operations)	-1.11257***	1.93723***	2.10053***
(Landside Inbound Freight)	(0.05603)	(0.05812)	(0.09649)
ln(Scale of Hub Operations)	2.34957***	-1.47802***	-2.07703***
(Seaside Outbound Freight to the U.S.)	(0.05957)	(0.06300)	(0.10370)
Outbound Feeder Line Diversity	0.38811***	-0.62870***	-1.03094***
(First Port, Outbound Feeder Lines)	(0.02759)	(0.04418)	(0.09352)
Inbound Feeder Line Diversity		-1.06390***	-0.15758
(First Port, Inbound Feeder Lines)		(0.02563)	(0.10027)
Inbound Hub Line Diversity	-0.38153***	0.69825***	-0.23765
(Last Port, Inbound Feeder Lines)	(0.03291)	(0.04538)	(0.14947)
Outbound Hub Line Diversity	0.07437	-1.45474***	0.82885***
(Last Port, Outbound U.S. Lines)	(0.04395)	(0.06939)	(0.17682)
Intermediacy		1.54623***	1.17037*
(Last Port)		(0.28516)	(0.58383)
Landside Distance	-0.31318*	-2.26894***	-4.19317
× Unit Value	(0.15655)	(0.66576)	(2.27385)
Long-haul Maritime Distance	-0.35306*	0.00172	-0.70437***
× Unit Value	(0.14573)	(0.03056)	(0.14849)
Short-haul Maritime Distance		-0.30859*	
(East Atlantic) × Unit Value		(0.15580)	
Short-haul Maritime Distance			0.43392*
(West Atlantic) × Unit Value			(0.19076)
Landside Distance	-0.01443***	-0.00932**	0.00742
× Shipping Volume	(0.00214)	(0.00315)	(0.00380)
Long-haul Maritime Distance	-0.00292***	0.00033**	0.00040
× Shipping Volume	(0.00061)	(0.00011)	(0.00029)
Short-haul Maritime Distance		-0.00113*	
(East Atlantic) × Shipping Volume		(0.00056)	
Short-haul Maritime Distance			-0.00281***
(West Atlantic) × Shipping Volume			(0.00069)
Landside Distance	-0.40729***	0.12698**	0.41587***
× Shipper Size	(0.03111)	(0.04287)	(0.04082)
Long-haul Maritime Distance	0.00514	-0.00235***	-0.00610**
× Shipper Size	(0.00610)	(0.00068)	(0.00197)
Short-haul Maritime Distance		0.00981	
(East Atlantic) × Shipper Size		(0.00542)	
Short-haul Maritime Distance			0.00435
(West Atlantic) × Shipper Size			(0.00657)
Long-haul Maritime Distance	0.02512***	-0.00592***	-0.03825***
× Panama-Crossing	(0.00581)	(0.00105)	(0.00456)
Short-haul Maritime Distance		-0.01430**	
(East Atlantic) × Panama-Crossing		(0.00544)	
Short-haul Maritime Distance			0.13131***
(West Atlantic) × Panama-Crossing			(0.01093)
Log Likelihood		-39,782.602	
Number of Cases		3,736,211	

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; § Random coefficients; Standard errors in parentheses.

Table 2-4 Effects of Hub-and-spoke configuration variables

Variable	Direct Routes	ETS Routes	WTS Routes
Scale of Landside Operations	(-)	(+)	(+)
Scale of Hub Operations	(+)	(+)	(+)
Outbound Feeder Line Diversity	(+)	(-)	(-)
Inbound Feeder Line Diversity	N/A	(-)	Not significant
Inbound Hub Line Diversity	(-)	(+)	(-)
Outbound Hub Line Diversity	Not significant	(-)	(+)
Intermediacy	N/A	(+)	(+)

to sea would occur with greater acuity at a port with larger SLO; hence, a bottleneck in landside operations may happen when a maritime operation like forwarding is not done synchronously. In such case, a larger SLO is symptomatic of landside congestion at the port, and this would negatively affect landside shipping along direct routes. For transferring shipments, on the other hand, landside, seaside and hub operations are physically separated between the first and final ports; as a result, the shipments may be less affected by landside congestion, so scale economies can arise with SLO. Moreover, I also find that the effect of SHO is larger along the direct routes (2.34957) than along ETS ($2.34957 - 1.47802 = 0.87155$) and WTS routes ($2.34957 - 2.07703 = 0.27254$), indicating a greater scale effect of hub operations on direct routes. By bypassing the transshipment process, shipping on a direct route entails much faster processing at the port, so a greater SHO can make direct shipping smoother and more efficient than in the case of a transfer at the port.

Second, the direction of the effect of shipping line diversity on route selection is mixed across diversity measures and route types. In some scenarios, more shipping line diversity would facilitate smoother shipping flows by enhancing the connectivity of ports in the maritime shipping network and by providing options of shipping lines to diverse destinations. In other scenarios, diseconomies may arise with congestion stemming from diverse shipping lines. On the aggregate, shipping line diversity may have a positive or negative effect on shipping flow depending on the type of routes and the diversity measures. For example, along direct routes, diversity effects are found to stem from the outbound feeder line diversity, but along ETS routes this happens only with inbound hub line diversity, and only with the outbound hub line diversity on WTS routes. Also, the outbound feeder line diversity is detrimental to shipping flows when shipments are transshipped (both on ETS and WTS routes), but the diseconomies are stronger along the WTS routes, indicated by a larger magnitude along WTS routes $(0.38811 - 1.03094 = -0.64283)$ than along ETS routes $(0.38811 - 0.62870 = -0.24059)$. An abundance of outbound feeder lines at the first port may create congestion and hinder shipping flow along both ETS and WTS routes but to a greater extent along the WTS routes, so that the first port can better facilitate shipping flow when its feeder operation is captive to fewer hub ports.

Lastly, given that shipping line diversity is estimated to have different signs, the hub-and-spoke shipping economies can ease the friction of distance on shipping flows in different ways across route types. Based on the direction of estimated coefficients in Table 2-4, a three-pronged schematic model of how the friction of distance on shipping is eased by the effects of hub-and-spoke configurations can be advanced (Figure 2-4). In each scenario, the hub-and-spoke system has a distinct shape that best fits the requirements of a

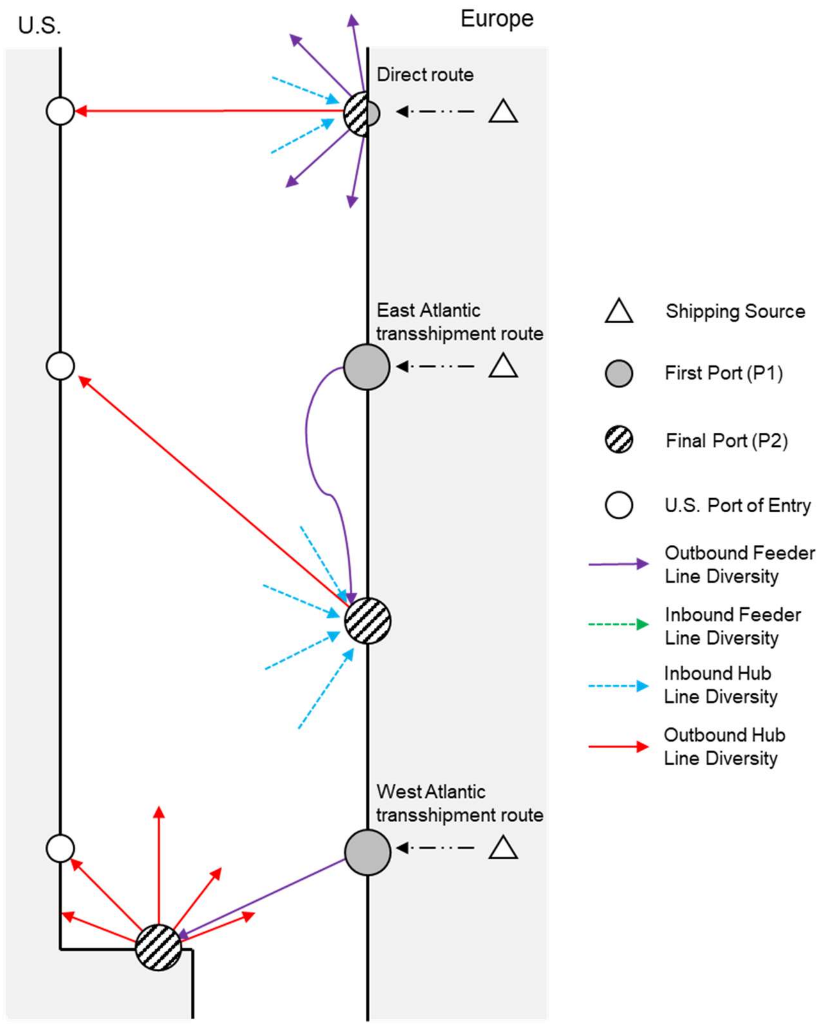


Figure 2-4 Schematic shapes of the hub-and-spoke system on each route

specific route type: on direct routes, it is in the form of a one-to-many feeder-hub connection (positive outbound feeder line diversity), along the ETS routes, a many-to-one feeder-hub connection (positive inbound hub line diversity), and finally, along the WTS routes, a one-to-many hub-destination connection (positive outbound hub line diversity). It can be argued that these configurations exist due to the difference in the hub operations of the East and West Atlantic final ports involved in trans-Atlantic trade shipping. As far as trans-Atlantic trade is concerned, the hub operations of East Atlantic ports serve mainly to collect shipments from different feeder ports and aggregate them as long-haul bulk shipments. Mirroring this configuration, the hub operation of the West Atlantic final port is mainly for redistribution of long-haul bulk shipments from Europe by breaking them into smaller shipments and distributing them to different U.S. destination ports.

2.6. Conclusions

The inverse relationship between distance and spatial interaction has been established as a stylized principle of geography that explains social and economic phenomena across space. By standard accounts, the distance friction stands as the most fundamental and dominant impedance factor governing spatial interactions in a broad range of circumstances. Recent observations of the augmented strength of distance on trade flows, dubbed the "distance puzzle," have prompted many economic geographers and trade researchers to revisit if and how spatial economic interaction is attenuated with distance friction, especially in the context of long-distance commerce. Even though the advances in transportation systems have been instrumental in facilitating the efficient long-distance movement of international freight, the details of the trade logistic process from location to location have been overlooked in the study of the relationship between distance and trade flows. In response to the debate on the distance puzzle, this paper posited that the hub-and-spoke distribution system, as a central component of the modern international logistic chain, has a crucial role in cost-space convergence between trade origin and destination by diminishing the friction of distance friction on trade flows.

My study focused on examining the influence of the hub-and-spoke configuration along trade routes on patterns of routing of trans-Atlantic trade shipments. On the basis of micro-level trajectories of freight shipments from Europe to the U.S., I examined choice patterns of freight routing in relation to the hub-and-spoke configuration of traversed ports along the route. The mixed logit model results established that hub-and-spoke configurations can ease distance friction of international freight shipping. It was found that effects of the port scale of operations and shipping line diversity are evident in reducing the friction of distance. However, I found that hub-and-spoke shipping economies arise differently across route types, so hub-and-spoke configurations should be set differently when hub-and-spoke shipping economies are to be maximized. Specifically, the SLO and SHO were found to significantly diminish the total cost of shipping between origin and destination, except the SLO having a negative effect along direct routes. Diversity effects mainly stem from the more diverse shipping lines serving the final port of export. On the East Atlantic, distance friction can be eased by the final port with more inbound hub line diversity, and on the West Atlantic, with more outbound hub line diversity.

This study provided important implications to economic geography and international transportation. First, distance between origin and destination is not the only factor that governs spatial trade flows, but the logistic process *en route* from point to point is influential in defining the trade relationship. As evidenced by the results of the analysis, the long-distance movement of freight takes place with logistic interactions between feeder and hub ports and transshipment activities along the route. Thus, in terms of spatial trade flows, geographical remoteness is not fully explained by distance between trade origin and destination, but the hub-and-spoke configuration also matters as a ‘dark’ distance factor.

Second, transshipment via a hub port can be a strategic choice option for promoting hub-and-spoke shipping economies and reducing the cost of long-distance commerce. It allows a shipping party to consider efficient logistic planning by taking advantage of scale economies and diverse shipping line services. In this regard, it is of practical significance to perceive the differential effects of hub-and-spoke configuration across route types and its potential impact on business activities in establishing strategic routing for international trade shipments. In the trans-Atlantic trade space of instance, a shipping line company or shippers may pursue a way to sustain a shipping line by building diverse feeder lines to a hub port in the East Atlantic or by promoting diverse shipping lines at Caribbean ports to enhance their redistribution functions.

Third, consideration of the hub-and-spoke distribution system is necessary for building export-oriented development policies. A local economy seeking to expand its intensive export-oriented business may not have high access to foreign markets if it lacks sufficient transportation infrastructure for long-distance trade logistics. As a way to overcome the geographical remoteness in the global market, a transportation development policy can be established to expand the hub-and-spoke logistics system. Rather than striving to establish direct routes to destination ports, setting a feeder connection to a strategic hub port where local shipments can easily be gathered and transshipped with diverse feeder line services may be a more effective strategy. Facilitating synchronized and coordinated feeder and inter-hub shipping lines could be one way to maximize the benefits of the hub-and-spoke shipping economies and reduce impedance from the distance friction.

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CHAPTER 3: STATE FAILURE, VIOLENCE AND TRADE: DANGEROUS TRADE ROUTES IN COLOMBIA

3.1. Introduction

Long-distance commerce thrives under the stable and reliable operation of a global logistic chain devoid of impediments. It capitalizes on a supply chain that has accelerated mobility, speed, capacity and reliability of freight shipping, but also where security is offered door to door (Cowen 2014, Birtchnell 2016). As the 9/11 terrorist attacks escalated security concerns, security of the logistic chains is no longer the purview of a single country's policy effort like blockading borders. Instead, it has become a matter of managing and monitoring flows of goods along any segments of trade corridors spanning across countries (Bigo 2001, Haveman and Shatz 2006). In this context, governments and international organizations have become more interested in the impacts of terrorist attacks, piracy, crime, and theft on freight mobility and in appropriate prevention measures against disruptions to assure the frictionless and seamless flow of international commerce (Cowen 2014).

In the light of the unprecedented internationalization of commerce and the ensuing integration of the global market, the inclination is to hold the view that international trade flows are no longer impeded by market barriers and geographic remoteness and are fully secure. It may largely be true in trade between developed countries today, where there are adequate supply chain infrastructure and institutions for long-distance shipping and secure operations, but it could be wishful thinking for many developing countries. Latin American countries are a case in point in this respect, where poor inland transportation systems increase freight shipping costs and uncertainty in the cargo logistics chain is holding back the opening to global markets and the growth potential of inland regions (Tiller and Thill 2015, Vega *et al.* 2019). Specifically, by the early 2000, Colombia exhibited one of the lowest indicators in terms of the number of kilometers of paved roads per worker (0.4 km). Peru and Guatemala surpassed Colombia's endowment with 1.1 km per worker, followed by Chile and Brazil (2.5 kms), Venezuela (3.6 km) and Argentina (5.9 km) (Pérez-Valbuena 2005).

Even though the traditional view in the trade literature has posited that tariff, quota (Anderson and Van Wincoop 2004), landlocked-ness (Kashiha, Thill, *et al.* 2016), international borders (Kashiha, Depken, *et al.* 2016), quality of logistical infrastructure (Limão and Venables 2001) constrain export activities and international commerce, I contend that insecurity is another significant impediment to border-crossing movement of goods. As more threats to international supply chains emerged after the 9/11 terrorist attacks, a number of studies have discussed the extent to which insecurity impacts commerce and freight mobility. For example, trade activities of Latin American countries are found hindered by the low quality of institutions and legal systems, lack of personal security, and prevalence of organized crime (Anderson and Marcouiller 2002). Moreover, a drastic rise in piracy activities in the water of the failed state of Somalia has escalated concern for the expansion of trade shipping costs because of the risk of attack and hijacking on vessels (Hastings 2009). In order to curtail risk from the Somali piracy, some shipping liners and shippers decided to re-route their vessels via the Cape of Good Hope despite the longer journey (Bendall 2010). Hence, disruption and exposure to such risk in any stages of the logistics chain can cause tremendous economic fallout, hike shipping costs, and restrict trade and shipping behaviors.

In this respect, I focus on the case of Colombia in 2006-2007 to determine how insecurity during this timeframe acted as an impediment to the movement of freight shipping in international commerce, as other tariff and non-tariff factors did. Much evidence has suggested that, for a number of years, Colombia's economic growth was persistently hampered by its state failure and by the limited effectiveness of institutions to control civil conflicts and organized crime (McLean 2002, Arnson 2004, Riascos and Vargas 2011). Domestic armed conflicts were reported in the area of main highways and ports, and trucking further inland experienced frequent interruptions, which were dubbed "*pesca milagrosa* [miraculous fishing]," by bombing, armed attacks, robbery, kidnapping, blockade, and extortion of tolls for passage and ransom by guerrilla groups (Rohter 1999, Rangel Suarez 2000, Feldmann and Hinojosa 2009, BBC News 2016). Since Colombia's production activities are concentrated in the Golden Triangle Area encompassing Bogotá, Medellín, and Cali, the three most important cities by population and GDP, export shipments to ports are highly exposed to the risk of obstruction associated with domestic armed conflicts. Given the heightened cost of risk, freight mobility in Colombia could be compromised by insecurity stemming from the unstable political environment, which in turn may curtail export activities and access to the global market.

In this context, this study examines the effect of domestic armed conflicts along trade corridors on freight mobility. I focus specifically on decisions made by shipping parties among possible shipping routes in response to insecure political environments on the landside. Matching Colombia-U.S. export shipping records and localized domestic armed conflict data in Colombia, I study at the micro-level how the corridor of freight shipping to seaports is influenced by the geography of domestic armed conflicts. I posit that the decisions pertaining to the port of export and port of transit on the one hand and to the shipping route leading to ports on the landside on the other hand are closely intertwined. Hence, I propose the hypothesis that shipping parties would seek to reduce their exposure to domestic armed conflicts along the shipping routes by shifting to other ports that can be accessed more securely, despite extended shipping distances. Using the sequence of ports that the freight shipment traverses as a proxy for its shipping route, I formulate and estimate a discrete choice model to examine the likelihood port choice along the route is influenced by the risk from insecurity and other covariates. I demonstrate on the basis of micro-level data that shipping routes exposed to higher risk of domestic armed violence have higher freight cost and distance friction and that cargo shipping is re-routed to further ports via safer routes. These re-routing behaviors have widened Colombia's regional disparity in freight mobility and have limited access to foreign markets, arguably discouraging export-oriented economic activities in inland areas.

The next section reviews the literature on the relationship between insecurity and commerce and provides background on Colombia's political and economic geography with a focus on its long-term political fragmentation and underdeveloped transport system. Here I also discuss preliminary findings on spatial patterns of the trade route choices and domestic armed conflicts from U.S.-bound export shipping and local armed conflict records in Colombia. Then, I present my modeling strategy to examine how export-bound shipping routes are influenced by the risk of domestic armed violence. The next section presents and discusses my core analytical results. In addition, I compute distance equivalences of the observed risk of domestic armed conflicts to measure the cost of the re-routing and I assess the extent to which access to global markets is restricted. The last section concludes with policy implications for institutions that support the secure operation of cargo shipping logistics and foreign aid support for transportation development.

3.2. Background

3.2.1. Theoretical Background: Insecurity as Trade Impedance

The study of international and interregional trade has long sought to identify the impediments to trade. Common findings are that trade flow is constrained not only by transport costs but also by implicit factors that impose a hidden tax on international commerce (Head and Mayer 2013). Anderson and van Wincoop (2003) observed that international borders restrict trade flows more than explained by formal impediments like physical distance, tariffs, and quotas alone. Bilateral trade between the Global North and South is also observed to be much more constrained than would be expected from differences in relative factor endowments (Anderson and Marcouiller 2002). In fact, a range of geographical and policy factors have been attributed to the hidden trade barriers, such as the quality of the logistical infrastructure (Limão and Venables 2001), tariff and trade policy relationships (Baier and Bergstrand 2001), international border, and landlocked-ness of countries (Christ and Ferrantino 2011, Kashiha, Thill, *et al.* 2016, Capello *et al.* 2018), and historical and colonial legacies (Head and Mayer 2013).

Insecurity has been discussed as a main impediment to international and interregional commerce in the larger context of the literature on institutions. As economic growth can be severely curbed when states fail to support adequate institutions to control violence and enforce laws (Knack and Keefer 1995, Blomberg *et al.* 2004, Berman *et al.*

2012), Anderson and Marcouiller (2002) argued that the lack of institutions in trading countries can lead to a heavy toll on international trade, like cases of hijacking of shipments, contract breaking, corruption and bribery extortion by customs officials. Especially, any types of violence, like external and internal conflicts and terrorist attacks, can cause a serious decline in trade since trading partners would be inclined to switch to more peaceful countries to avoid risk (Blomberg and Hess 2006). Thus, incidents of violence can raise trade barriers as much as tariff, quota, and transport costs do.

Previous studies have examined different extreme cases of inadequate institutions to show that violence and insecurity have a negative effect on trade. Anderson and Marcouiller (2002) estimated that the trade volume of Latin American countries is 30% lower than European Union countries, owing to their low institutional quality, and more specifically, deficiencies in government transparency, reliability of the legal system, personal security, and fight against organized crime. Country-level gravity model results also indicated that trade volumes are significantly reduced by the threat of terrorist events (Blomberg and Hess 2006, Mirza and Verdier 2014). Blomberg and Hess (2006) estimated that terrorism and internal and external conflicts depress trade flows as much as a 30% tariff on trade.

Weak institutions, possibly leading to endemic violence and corruption, can restrict freight mobility and impact patterns of trade shipping. The rise in Somali piracy has patently shown how violence hinders international freight shipping and trade flows. Besley *et al.* (2015) found that shippers incurred extra maritime shipping costs for the risk premium from the Somali piracy and diminished economic profit from the international trade, as the Somali government lost its state power to control pirate activities. Bendall

(2010) estimated the additional freight rate levied on shipping lines to avoid the risk of piracy by re-routing via the Cape of Good Hope. Freight mobility is also discouraged by corruption. South African firms are found to be willing to re-route their shipping to more distant ports to avoid the uncertainty of bribery payments at corrupt ports despite the higher transport costs (Sequeira and Djankov 2014). These cases emphasize the importance of strong institutions as a necessary condition for freight mobility and access to the international market through port-bound and inter-port transport systems.

3.2.2. Context: State Failure and Transport Geography of Colombia

Colombia is known for its deep-seated history of fragmented political landscape, the prevalence of violent crimes, and lagging economic growth ruined by illegal drug trade (Richani 2007). A number of active left-wing insurgent groups emerged in the early 1960s with different political ideologies and stance vis-à-vis the national government, like *Fuerzas Armadas Revolucionarias de Colombia* [Revolutionary Armed Forces of Colombia] (FARC), *Ejército Popular de Liberación* [Popular Liberation Army] (EPL) and *Ejército de Liberación Nacional* [National Liberation Army] (ELN). Paramilitary groups like *Autodefensas Unidas de Colombia* [United Self-Defenses of Colombia] (AUC) were also organized for self-defense and protection of local landowners against the left-wing guerrilla groups.

Regardless of their political stance, all armed groups were suspected of direct involvement in numerous cases of serious violent crimes in Colombia, such as death threats, homicides, massacres, forced recruitment, hijacking, kidnapping, bombing, road blockading, and narcotrafficking (Lozano-Gracia *et al.* 2010). The rugged terrain of the Andes and the dense Amazon forest are favorable to irregular warfare, so they could take advantage of the geography in guerrilla activities (O'Sullivan 1983). Since civilians living in sporadic urban settlements could be easy targets, the insurgent groups could not only easily wage predatory acts on civilians but also efficiently react to the government's suppression attempts (Holmes *et al.* 2010). Frequent combats between insurgents, paramilitary groups, and the government armed forces have escalated a security concern and detrimental economic impact on Colombia.

With Colombia's well-known poorly managed inland transportation infrastructure, political instability and state failure have seriously degraded inland freight mobility. Moreover, the lack of dual carriageways or the poor condition and the obsolescence of the land roads represent additional costs to the trucking companies and, in turn, disadvantages in the competitiveness of the country (Yepes *et al.* 2013, García-García *et al.* 2015). According to Ramírez-Giraldo *et al.* (2021), transport infrastructure in Colombia suffers from institutional failures of planning, regulation and corporate governance that hinder the development of this sector, which in turn have led to a historical lag in transportation infrastructure in comparison to the international context. The Colombian government could not guarantee security and enforce the rule of law along inland trade corridors, and inland freight shipping from the Golden Triangle Area cannot avoid the risk of disruption. A number of violent crime and conflicts are reported on main highways and in ports, such as road blockading, truck hijacking, bombing, attacks, robbery, and combats between armed groups (see Selsky 2002, Associated Press Archive 2003, 2005, Associated Press News 2003, EFE News Services 2004, 2006, 2009a, 2009b, 2009c, de Leon 2006, Cambio Weekly 2009). Guerrilla groups were reported to weight transportation companies' freights and to force them to pay irregular tolls on highways and rivers (Rangel Suarez 2000). If the companies were reluctant to pay tolls, they threatened to destroy and impound the companies' vehicles.

Insecurity around ports is also a great concern with freight shippers. In particular, the port of Buenaventura, the only gateway container port to the Pacific, has experienced extreme insecurity. A union of Colombian insurance companies reported that Buenaventura has been the port that generates the highest number of payments for events related to theft than any other port in the country (Sierra 2013). Even though Buenaventura is the most straightforward port to export from the Golden Triangle Area distance-wise, the operation of export through Buenaventura has frequently been obstructed by crime and violence. Buenaventura has been exploited as one of the main channels of illicit trade for cocaine export, and the city has remained a hub of gang activities tied to narcotrafficking (Zeiderman 2016, McVeigh 2018). Despite the Colombian government's attempt to demobilize paramilitary groups, the remaining bands have persisted in controlling local residents, imposing forced recruitment and preying on local businesses (Schoening 2014). The countryside of Buenaventura has frequently fallen under the control of the FARC (Zeiderman 2016). The city even experienced a massive attack on the infrastructure that resulted in a citywide power outage (AFP 2015).

3.2.3. Empirical Setting: Spatial Patterns of Domestic Armed Conflicts and Trade Freight Shipping

3.2.3.1. Colombia-U.S. Freight Shipping Data

To study export shipping patterns from Colombia to the U.S., I retrieved records of maritime cargo shipping between these countries from the Port Import Export Reporting Services (PIERS) database. The PIERS database consists of bills of lading of freight imported through ports where the U.S. Customs and Border Protection offices are located.

Each record has details on the shipping process from the origin to the U.S. destination port, including addresses of shippers, forwarding ports of exporting countries, intermediate ports before entering the U.S., commodity types described by the Harmonized Commodity Description Coding System (HS) codes, volume and weight of the cargo. The shipping records were recoded to clearly indicate their shipping trajectories, by identifying the location of shippers, forwarding ports in Colombia, intermediate transfer ports, and U.S. destination ports. I first collected 28,656 bill-of-lading records of cargo imported through U.S. ports from July 2006 to June 2007, right after Colombian domestic armed conflicts had intensified. Idiosyncratic shipment cases are excluded, such as empty containers, non-containerized cargo, cargo with no information on the estimated freight value or weight, and cargo transshipped at remote ports in East Asia and Europe. This produces a dataset of 26,109 bill-of-lading records of containerized cargo. Shipments of non-containerized cargo or bulk products, such as coal and oil, are not considered in the study because their production origins are limited in a few locations and their shipments are captive to a specialized port where bulk products can be handled.

I should note that Colombia's geography has a distinctive setting as far as export shipping patterns are concerned. Colombia faces both the Pacific Ocean and the Caribbean Sea, but ports on the Pacific coast and on Caribbean coast are physically disconnected by the Darién Gap, an extremely dense rainforest and watershed area with very sparse human settlement. No road infrastructure exists in the Darién Gap, so inland shipping routes to the Pacific and Caribbean ports are completely separated. By passing the Panama Canal, cargo shipping from Colombia to the U.S. follows any of a number of routes, from inland areas via Colombian ports on either the Pacific or Caribbean coast and the Panama Canal, finally to U.S. ports on the Pacific, the Atlantic or the Gulf coast (Figure 3-1). For example, between July 2006 and June 2007, cargo originating in Bogotá was shipped to the U.S. along with a number of different maritime routes, in fact, 202 unique combinations of forwarding, intermediate, and U.S. ports trade routes. All cargoes from Colombia were processed through 318 different maritime routes. Examining various possible trade routes allows me to see how shipping route choices are made among broad choice sets and how shipping is re-routed in response to differentiated levels of exposure to the risk of domestic violence.

Colombia's land-based transportation system is configured in such a way that enables me to directly observe the relationship between freight mobility and the incidence of unstable domestic environments, without any interferences of political relationships with third countries or shipping across the territory of third countries. The inland segment of cargo shipping from Colombia to the U.S. is confined to Colombia's domestic transport system. Between July 2006 and June 2007, all Colombia-U.S. export cargo was forwarded exclusively to Colombian ports without crossing the border into a neighboring country. Also, cargo sources are overwhelmingly concentrated in the Golden Triangle Area, deep in the Andean region, rather than in the coastal areas. According to the PIERS data used in this study, 10,920 out of 26,109 U.S.-bounded shipments from July 2006 to June 2007 were shipped from Bogotá, Medellín and Cali, and accounted for 40,643.57 TEUs or 52.33% of the total freight cargo. Most freight is hauled by truck because of the low quality of railway and waterway infrastructures (Vega *et al.* 2019), and inland shipping to ports is therefore highly susceptible to influences from Colombia's political and transport geography. Notice that by the early 2000, only 15% of the road network in Colombia was paved among the

Figure 3-1 Spatial distribution of U.S.-bound freight shipping departure points (July 2006–July 2007)

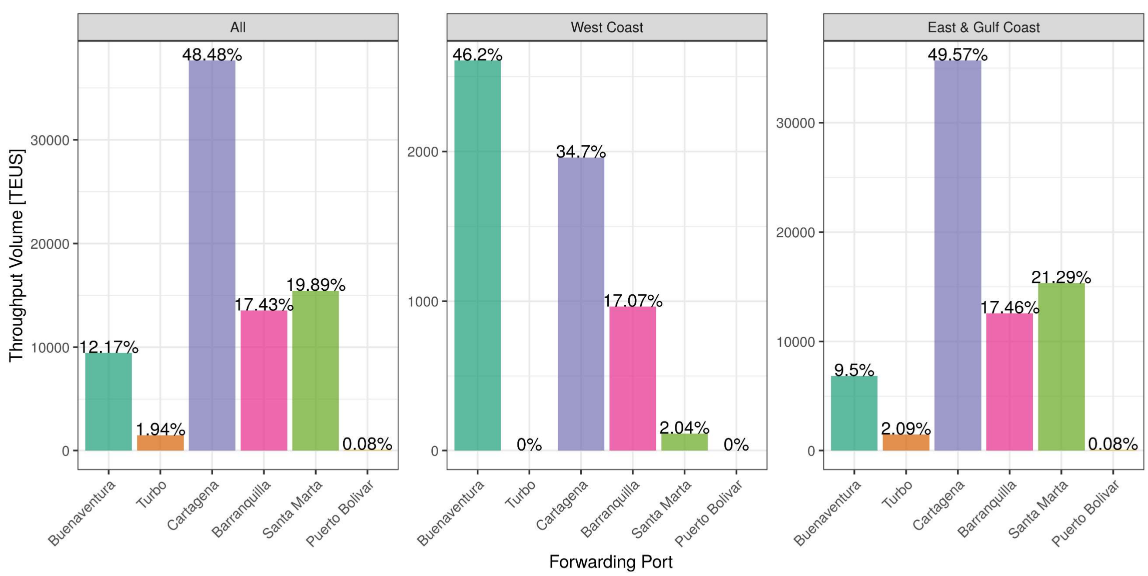

Figure 3-2 Port forwarding patterns of U.S.-bound freight shipping from Colombia (July 2006–June 2007)

total 166,233 km (Cárdenas *et al.* 2005). Those factors may explain why "internal transport costs exceed international transport costs, a counterintuitive result for a country where the distances traveled internally are less than those traveled in maritime transport" (García-García *et al.* 2017).

Even though the Pacific and Caribbean coasts are topographically separated by Panama and the Darién Gap, shipping through each coastal range of ports is not necessarily tied to the corresponding range in the U.S. My dataset reveals that a significant volume of cargo is cross-shipped to the other side via the Panama Canal (Figure 3-2). Even though municipalities in the Golden Triangle Area are much closer to Buenaventura on the Pacific coast, a disproportionate number of U.S.-bound exports is forwarded through Caribbean ports, like Cartagena, Barranquilla, Turbo and Santa Marta (84.92%), rather than Buenaventura (13.82%). Even when the final destinations are U.S. West Coast ports, 53.05% of the freight is forwarded through ports on the Caribbean, despite considerably extended maritime voyages through the Panama Canal. This implies that Pacific ports starkly lagged behind ports on the Caribbean Coast in handling freight, and that freight mobility on the Pacific coast is severely restricted. Possibly, Buenaventura's lower efficiency in logistic operations may cause this, yet the underperformance of Pacific ports is still notable.

3.2.3.2. Colombian Domestic Armed Conflict Data

I use the Uppsala Conflict Data Program (UCDP)'s Georeferenced Event Data (GED), which contains geolocated point-based armed conflict records to see the empirical trend in domestic armed conflicts in Colombia. UCDP has collected worldwide armed conflict cases annually since 1989 from global newswire and local media reporting, non-governmental and intergovernmental organization reports, and field reports (Sundberg and

Melander 2013, Högbladh 2019). The geographical coordinates are identified by the place or administrative division names reported in the sources. I use detailed information about domestic armed conflicts in UCDP GED, such as the total number of fatalities, warring parties, start and end dates of the events.

In the 2000s, Colombia experienced an extreme level of violence between Colombian armed forces, insurgent, and paramilitary groups, as shown by the time-series trend of the armed conflicts (Figure 3-3). While the Uribe administration (2002–2008) expanded counterinsurgency operations, the number of casualties and violence incidences reached their peak in 2002 and 2004, respectively (Dube and Naidu 2015). The preponderance of violent incidents and casualties came from combats between Colombia armed forces and insurgent groups, but the number of civilian attacks was also quite high. The incidence of civilian attacks was most severe in 2002, but the number of casualties of civilian attacks remained large until 2006. The violence between paramilitary and insurgent groups faded away in 2006, when AUC was demobilized by the Colombian government. The mapping of domestic armed conflicts between 2002 and 2007, when a counterinsurgency campaign was initiated, and domestic armed conflicts reached their peak, shows that the events were disproportionately clustered in the central part of the Andean region (Figure 3-4). Since the area is mountainous but also the most populated, its geography provides an environment favorable to the guerrilla warfare of the insurgent groups (O'Sullivan 1983). This area is also the epicenter of Colombia's economy, where Bogotá, Medellín, and Cali are located, so civilians and businesses are easy targets of insurgent groups, as seen by the concentration of civilian attacks in this area. The mapping confirms that armed conflict events tended to occur along roads and near populated areas

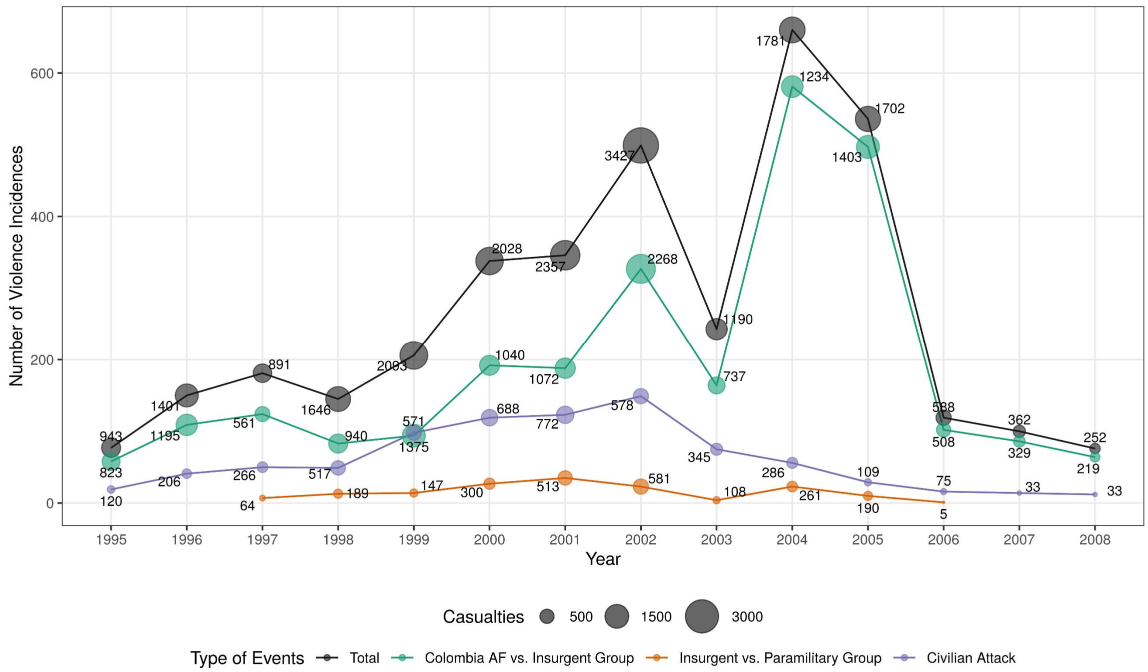

Figure 3-3 Time-series trend of domestic armed conflicts in Colombia (1995–2008)

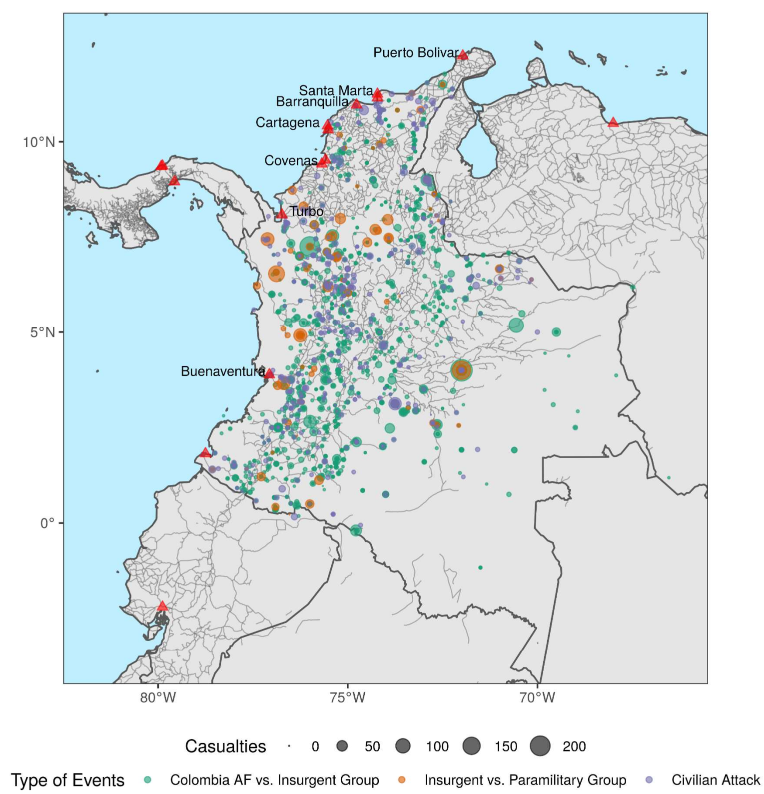

Figure 3-4 Spatial pattern of domestic armed conflicts in Colombia (2002–2007)

rather than deep in the Amazon forest. This implies that the exports starting from or passing through the central part of the Andean region could be exposed to insecurity from the armed conflict events.

3.3. Research Design and Implementation Issues

3.3.1. Discrete Choice Model of Port Pairs aligned with Shipping Routes

To restate my objective, I study the effect of Colombia's domestic armed conflicts on commerce. I do so by analyzing export shipping routes across land and water over a twelve-month period in the form of switches between alternatives in response to localized risks of human and material loss and of transit delays brought about by violent events. On the premise that decisions pertaining to the choice of ports and to the port-bound routing on the landside are made at once, and given the configuration of Colombia's land-based transportation systems, I argue that the re-routing of shipments for safety reasons would also entail using the services of other ports. Hence, the analysis focuses on the choice of ports along the logistics chain of shipments from a Colombian source to the U.S.

International freight shipping involves multimodal logistic processes, such as land-based and maritime shipping and transshipment at ports on the cargo's voyage. For my purpose, I conceptualize the route of a shipment as a sequence of three segments (Figure 3-5): land-based segment (shipping origin–forwarding port), initial maritime segment (forwarding port–intermediate port), and final maritime segment (intermediate port–U.S. port of entry). In my micro-level trade dataset, the shipping route choices are represented by tripartite joint choices of forwarding, intermediate, and U.S. ports of entry. Since the PIERS data do not provide a detailed record of the spatial trajectory that a shipment took, I use the sequence of traversed ports as a proxy for the shipping route.

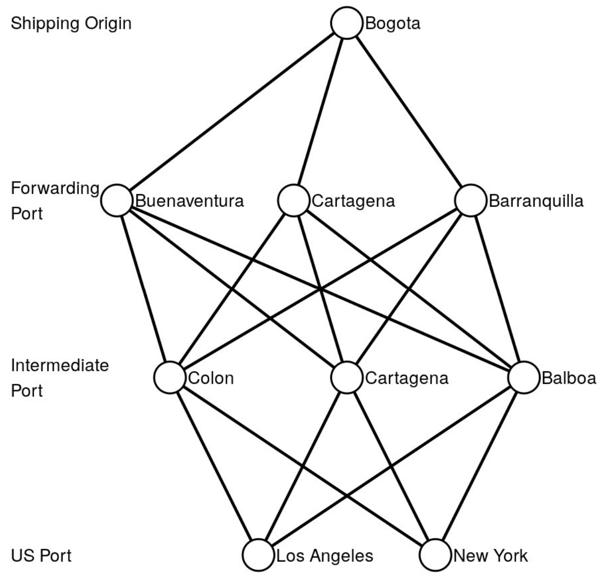

Figure 3-5 Illustration of the tripartite join choice of ports along the route: An example of possible shipping routes from Bogota, Colombia

PIERS data do not provide sufficiently reliable information on the U.S. consignee location; hence, the last location on an observed shipping route that can reliably be used is the U.S. port of entry. Since the choice of the port of entry heavily depends on the shipment's ultimate destination, I do not analyze the choice of the U.S. port of entry but include it instead as an exogenous variable in the model. Given that the shipment source and final U.S. port of entry are given and taken as exogeneous, the shipping route choice problem boils down to a choice of the two nodes of forwarding and intermediate ports. My focus being on the choice of traversed ports along the route, the choice set is then formed of all possible combinations of forwarding and intermediate ports. By doing so, I do not consider the choice of mode nor the specific set of transportation links traversed between two ports.

Here I assume that a port pair choice along each shipment's route is made independently of all the others. The utility of routing a shipment i on route j formed of a pair of traversed forwarding and intermediate (transshipping) ports is defined as follows:

$$U_{ij} = V_{ij} + \varepsilon \tag{3-1}$$

where U_{ij} is the utility of shipment i gained from choosing alternative j, V_{ij} is the deterministic part of the utility, and ε is the random component. When the shipment source and the U.S. port of entry l are given exogenously, the shipper of i will choose the alternative whose utility is the largest among all alternatives in the choice set J. Following a standard logit formula (Train 2009, Ortúzar and Willumsen 2011), the probability of choosing the route j^* can be expressed as follows:

$$P(y_{ij^*} = 1) = \frac{\exp(U_{ij^*})}{\sum_J \exp(U_{ij})} \tag{3-2}$$

where y_{ij^*} is a dummy variable indicating that trade route j^* is chosen among the choice set J and $\sum_J y_{ij} = 1$.

3.3.2. Model Specification: Utility Function of Shipping Route Choice

To test my hypothesis on the effect of domestic armed violence on commerce, I specify the utility of a shipping route alternative with a number of factors, including the core variable of risk of domestic armed conflicts, as control variables such as shipping distance, port features, and hinterland and foreland geography along the spatial extent of the shipping routes. I should note two additional assumptions made because of the limitations of the PIERS data. First, the shippers are assumed to send their cargo to Colombia's forwarding ports by truck. Inland container cargo is predominantly shipped by this mode in Colombia because of the low quality or absence of railway and waterway infrastructures (Vega *et al.* 2019). Since the PIERS data do not specify how cargo was hauled to ports before sailing off at the forwarding ports, this assumption is the best approximation to reality. Second, land-based shipping is assumed to follow the shortest path between the source and the forwarding port. Likewise, in my data, I can only locate the nodal points of forwarding and intermediate ports along the trade routes with sufficient precision, not the whole detailed trajectories of cargo movements. To measure geographical proximity between nodal points, I use the shortest-path distances along with the inland road network and maritime voyage network, respectively. Even though the shortest path routes may not be the actual routes taken, they can indicate how shipping from one point is geographically accessible to other points.

Following basic model specifications of traditional port choice studies (Malchow and Kanafani 2001, 2004, Steven and Corsi 2012, Kashiha, Thill, *et al.* 2016), I define the deterministic part of the utility function as follows:

$$V_{ij} = V_{ij}\left(r_{ij}, \boldsymbol{D}, \boldsymbol{X}\right) \tag{3-3}$$

where r_{ij} is the risk of domestic armed conflicts along the land-based shipping route between the shipping origin and the forwarding port when the shipment takes route j, $\boldsymbol{D}$ is the covariates of either shortest-path trucking or maritime voyage distances, and $\boldsymbol{X}$ is a vector of other shipment- and alternative-specific control covariates.

I first specify the linear effects of the shipping distances and of the risk on the utility:

$$V_{ij} = \gamma_1 d_{ij1} + \gamma_2 d_{j2} + \gamma_3 d_{ij3} + \phi r_{ij} + \eta_{ij} \tag{3-4}$$

where d_{ij1} is the shortest-path trucking distance from the shipping origin to the forwarding port, d_{j2} and d_{ij3} are the shortest-path maritime voyage distances between forwarding and intermediate ports and between intermediate port and the U.S. port of entry when shipment

i takes route j, respectively, and η_{ij} is the error term. Each parameter γ captures a linear distance friction effect or unit freight cost per distance, and ϕ denotes the linear effect of the risk on the utility. In addition to the linear effects, I capture the interaction effects between the risk and other covariates as discussed hereafter.

The error term η_{ij} in Equation (3-4) can be decomposed into three parts as follows:

$$\eta_{ij} = \eta_{ij}(r_{ij}, \boldsymbol{D}, \boldsymbol{X}) = u_i(r_j, \boldsymbol{X}_i) + v_j(\boldsymbol{X}_j) + w_{ij}(\boldsymbol{D}, \boldsymbol{X}_i, \boldsymbol{X}_j) \qquad (3\text{-}5)$$

where u_i captures additional marginal effects of the risk interacted with the shipment-specific covariates $\boldsymbol{X}_i$, v_j accounts for the effects of the alternative-specific control covariates $\boldsymbol{X}_j$, w_{ij} denotes the effects of the other control covariates interacted with the distance terms. I specify the additional marginal effects of the risk in Equation (3-5) by interacting with the unit value of the shipment as follows:

$$u_i = \lambda \times r_{ij} \times \pi_i \qquad (3\text{-}6)$$

where π_i is the unit value of shipment i. To account for the effects of the alternative-specific controls, $v_j(\boldsymbol{X}_j)$, I looked at including a range of port-related variables or route-related characteristics, like port capacity and throughput, port efficiency indicators, transshipment, and crossing of the Panama Canal. However, due to the limited availability of port- and route-related information, I control alternative-specific fixed effects by using dummy terms for each alternative j, $v_j(\boldsymbol{X}_j) = v_j$, instead. This ensures the estimation captures sufficiently well the unobserved time-invariant route-related characteristics and therefore avoids an omitted variable bias. Since the distance between forwarding and intermediate ports, d_{j2}, is specific to alternative j, the distance effect $\gamma_2 d_{j2}$ in Equation (3-

4) is absorbed in the alternative-specific fixed effect term, v_j, and it is thus removed from the utility function in Equation (3-5).

For the remaining part, w_{ij} in Equation (3-5), the specification serves to control shipper- and port-specific covariates. Since $\boldsymbol{X_i}$ and $\boldsymbol{X_j}$ are case-specific (shipment-specific) and alternative-specific variables, respectively, I cannot directly estimate their linear effects, but instead I capture them by interacting with the landside trucking and port-to-port voyage distances. Hence, I specify the w_{ij} term as follows:

$$w_{ij} = d_{ij1} \times \boldsymbol{X_1} \times \boldsymbol{\beta}_1 + d_{j2} \times \boldsymbol{X_2} \times \boldsymbol{\beta}_2 + d_{ij3} \times \boldsymbol{X_3} \times \boldsymbol{\beta}_3 \qquad (3\text{-}7)$$

where $\boldsymbol{X_1}$, $\boldsymbol{X_2}$ and $\boldsymbol{X_3}$ are shipment- and alternative-specific covariates interacted with landside distance, maritime distances d_{j2} and d_{ij3} between forwarding and intermediate ports and between intermediate ports and U.S. ports of entry, respectively, and $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$ and $\boldsymbol{\beta}_3$ are the corresponding coefficients. I treat the shipment volume and the unit value as covariates for all three distances. Also, to account for additional costs that may arise from economies of scale stemming from the size of shippers, from transshipment at intermediate ports and from the crossing the Panama Canal, I added the shipper size, dummy variables for transshipment, for crossing the Panama Canal westward (from the Colombian Caribbean to the U.S. Pacific Coast), and eastward (from the Colombian Pacific to the U.S. East and Gulf Coast) as covariates in $\boldsymbol{X_1}$.[1]

After substitutions, the final model synthesizing Equations (3-4) – (3-7) is given by:

[1] The shipper size, transshipment and Panama Canal crossing dummy variables exhibit high collinearity with the alternative-specific fixed effect dummy variables when they are interacted with the two maritime distances, d_{j2} and d_{ij3}. These variables interacted with d_{j2} and d_{ij} are therefore left out of the model specification.

$$V_{ij} = \gamma_1 d_{ij1} + \gamma_3 d_{ij3} + \phi r_{ij} + \lambda \times r_{ij} \times \pi_i + v_j + d_{ij1} \times \boldsymbol{X_1} \times \boldsymbol{\beta}_1 + d_{j2} \times \boldsymbol{X_2} \times \boldsymbol{\beta}_2 + d_{ij3} \times \boldsymbol{X_3} \times \boldsymbol{\beta}_3 \quad (3\text{-}8)$$

The key variables in this model are the risk r_{ij}, landside distance d_{ij1} and maritime distance d_{ij3}, and the main coefficients of interest are ϕ, γ_1 and γ_3.

I should note several important considerations regarding the estimation of this discrete choice model. First, owing to the structure of the choice set, the assumption of independence of irrelevant alternatives (IIA) is generally not going to hold. The IIA assumption is an important basis for the conditional logit model to provide consistent estimation of the effects regardless of how the choice set is built. However, the IIA assumption is not likely to hold in my shipping route problem because choice alternatives are pairs of forwarding and intermediate ports, and some alternatives may be correlated by sharing either a forwarding port or an intermediate port. I can relax the IIA assumption by estimating a mixed logit model instead. This model does not depend on the IIA assumption, because the ratio of mixed logit probabilities depends on all alternatives, regardless of how the full choice set is defined (Train 2009). Also, the mixed logit model estimates individual-specific coefficients by allowing random taste variation across individual cases, so I can see how the distance friction and route risk effects vary across shipments. With the mixed logit model, I impose individual-specific (shipment-specific) coefficients to the risk and the two distance terms as follows,

$$V_{ij} = \gamma_{i1} d_{ij1} + \gamma_{i3} d_{ij3} + \phi_i r_{ij} + \lambda \times r_{ij} \times \pi_i + v_j + d_{ij1} \times \boldsymbol{X_1} \times \boldsymbol{\beta}_1 + d_{j2} \times \boldsymbol{X_2} \times \boldsymbol{\beta}_2 + d_{ij3} \times \boldsymbol{X_3} \times \boldsymbol{\beta}_3 \quad (3\text{-}9)$$

Note that, in this formulation, γ_{i1}, γ_{i3} and ϕ_i replace γ_1, γ_3 and ϕ in Equation (3-8). I use the triangular distribution for estimating shipment-level coefficients γ_{i1}, γ_{i3} and ϕ_i to avoid having extreme outliers around the mean, like with the normal or log normal distributions (Train 2009, León and Miguel 2017).

3.3.3. Risk-to-Distance Equivalence: Trade-off between Risk and Distance

What is the price of exposure to risk? How much is a shipper willing to extend its landside or maritime shipping distance to avoid the risk of violent acts perpetrated by political factions? Taking an approach similar to the value of statistical life by León and Miguel (2017), I compute risk-to-distance equivalences (RDE) that measure the trade-off relationship between the risk and landside or maritime shipping distance. RDE is formally defined as follows:

$$RDE_i \equiv -\frac{\Delta d_i}{\Delta r_i} \tag{3-10}$$

where Δd_i is the change in landside or maritime shipping distance to reduce the risk Δr_i along the land-based or maritime shipping route. For the sake of the tractability of RDE estimation, I remove terms interacted with r_{ij}, d_{i1} and d_{i3} and leave all others as in Equation (3-9) and get:

$$V_{ij} = \gamma_{i1} d_{ij1} + \gamma_3 d_{j3} + \phi_i r_{ij} + v_j + d_{j2} \times \boldsymbol{X_2} \times \boldsymbol{\beta}_2. \tag{3-11}$$

Setting all variables other than the landside shipping distance d_{j1} and risk r_{ij} fixed in Equation (3-11) to facilitate the comparative statics, the change in utility is expressed by total differentiation as follows, when the shipment is switched from one alternative to another:

$$\Delta U_i = \gamma_{i1} \Delta d_{i1} + \phi_i \Delta r_i. \tag{3-12}$$

If $\Delta U_i = 0$,

$$\frac{\phi_i}{\gamma_{i1}} = -\frac{\Delta d_{i1}}{\Delta r_i} = RDE_{i1} \quad (3\text{-}13)$$

where RDE_{i1} denotes the landside RDE. A similar formulation can be applied to the maritime RDE:

$$\frac{\phi_i}{\gamma_{i3}} = -\frac{\Delta d_{i3}}{\Delta r_i} = RDE_{i3} \quad (3\text{-}14)$$

where RDE_{i3} indicates the maritime RDE. By estimating the coefficients of Equation (3-11) through the mixed logit model, the mean landside and maritime RDEs are given by the estimated mean coefficients γ_1, γ_3 and ϕ, which allows me to estimate the overall trade-off relationship, but I can also obtain the distribution around these mean measures by estimating the landside and maritime RDEs of each individual shipment from individual coefficients γ_{i1}, γ_{i3} and ϕ_i. Given that the landside and maritime shipping distances have a negative effect on the probability of choosing a route, if the risk also has a negative effect, landside and maritime RDEs would have a positive value. A higher value of the risk effect ϕ_i would return higher value of RDE.

3.3.4. Data, Variables and Measurements

My model investigates records of export shipping from Colombia to the U.S. and their route trajectories retrieved from the PIERS database. I collected bill of lading records imported through U.S. ports from July 2006 to June 2007. The choice pair of forwarding and intermediate ports in each bill of lading is extracted and used as a dependent variable. I exclude cases when shipments are transshipped at ports on other continents (e.g., South Korea, Germany, Spain, and Belgium), are not containerized, or consist of empty containers. My shipping data include 26,109 bills of lading, 77,661.67 TEUs (Twenty-foot

Equivalent Units), from 79 municipalities, 6 Colombian forwarding ports, 24 intermediate ports of Colombia and other foreign countries, and 26 U.S. ports of entry.

For the risk of domestic armed conflicts r_{ij}, the domestic armed conflict cases recorded in UCDP GED are used. I measure the total casualty counts of domestic armed conflicts within 20 km buffers around the shortest-path landside shipping routes. Since my focus is to detect the change in route choice patterns in response to risk, only armed conflict cases that occurred between July 2005 and June 2006 are considered. The shipping route and port choice is a long-term decision that accompanies the corporate contracts between shippers, shipping lines, and port authorities (Tongzon 2009), so they cannot be changed promptly right after a violent event has occurred. Hence, it is more appropriate to consider the cases with a time lag before shipping occurs. Other sources report on armed conflict cases, like the *Centro de Estudios sobre Desarrollo Económico* [Center for Economic Development Studies, CEDE] (2013), but their data are released after aggregation at the municipality level. Since UCDP data show strong correlation with CEDE armed events and similar spatial distributions, while also being more spatially disaggregated, UCDP data are deemed to be the best dataset to measure the route-level risk in my study.

For the landside shipping distance d_{ij1}, I measure shortest-path distances between shipment source and forwarding port along the road network from the Global Roads Open Access Dataset (CIESIN-ITOS 2013). Since Colombia has a rugged terrain that potentially degrades the speed and efficiency of trucking, I use a distance measure penalized according to slope, following an approach similar to Tao *et al*. (2016). I first split each road link by 5-km segments and compute a penalized distance by weighting the 5km segment by impedance factors according to the slope between the two endpoints (Table 3-A1). The shortest-path distance is calculated by summing the penalized network distances of segments. The slope information is calculated from the USGS Digital Elevation SRTM Dataset (USGS 2020). The maritime voyage distances d_{j2} and d_{ij3} are measured by the port-to-port shortest-path network distances from the Global Shipping Lane Network Dataset (Oak Ridge National Laboratory 2000).

The alternative-specific control covariates $\boldsymbol{X}_j$ include three dummy variables indicating whether transshipment takes place, whether the shipment should cross the Panama Canal westward (from the Colombian Caribbean coast to the U.S. West coast) and eastward (from the Colombian Pacific coast to the U.S. East coast) to reach the U.S. port of entry. The shipment-specific control covariates $\boldsymbol{X}_i$ include unit value of the shipment, reported shipment value by weight ($/kg), and shipper size (TEU), collected or computed from the bills of lading from July 2006 to June 2007. The shipper sizes are measured by the total freight shipment volume (TEU) by shippers in the dataset. When running models on subsets of the full dataset by commodity type, I use the first two-digit HS codes and reclassify them into 10 categories by the commodity characteristics (Table 3-A2). Descriptive statistics are reported in Table 3-A3.

3.4. Empirical Results

3.4.1. Main Results

I start with reporting my main regression results based on the full dataset (Table 3-1). As presented in Equation 3-9, I include four types of explanatory variables: landside and maritime shipping distances, risks, alternative-specific fixed-effects, and alternative- and shipment-specific controls interacted with distance terms. To check the model robustness and omitted variable bias, I run four models that either include or exclude 1) route risk interacted with unit value of the shipment and 2) a set of shipment-specific controls interacted with the three shipping distance terms, respectively. Thus, column 1 excludes both, and column 4 includes all, while column 2 only includes the route risk interacted with the unit value, and column 3 only includes alternative- and shipment-specific controls interacted with the shipping distance terms. With this testing design, I confirm that the effects of the route risk and of the marginal route risk by the unit value are consistent across model specifications. Hence, my main results are free from omitted variable bias, and they can therefore be considered robust.

In line with the literature, I find significant effects of distance impedance on port pair choice and by the same token on the shipping route. Both landside and maritime shipping distances commonly exhibit an inverse effect, implying a strong preference for shorter shipping distances throughout both stages of shipping. However, the magnitude of these friction effects is found fairly different across land and water. Estimation results (Column 4 in Table 3-1) indicate that the odds of choosing a port pair are decreased by 2.43% if the landside shipping distance is increased by 1 km ($e^{-2.4609/100} - 1 = -2.43\%$), while 1 km extension of the final maritime shipping distance has a much smaller effect, namely a 0.06% decrease in the odds ($e^{-0.0568/100} - 1 = -0.06\%$), all other effects being held constant. This indicates that the landside shipping segment accounts for a far greater portion of the total shipping cost than the maritime shipping segment despite shorter distance, which is consistent with a wide body of literature on this matter, such as García-García *et al.* (2017) and Vega *et al.* (2019).

Table 3-1 Port pair choices and perceived risk: Main results of the mixed logit model

		(1)	(2)	(3)	(4)
Distances	Landside Distance§	-2.2177***	-2.2670***	-2.3270***	-2.4609***
	(d_{ij1}, Origin – Forwarding Port)	(0.0314)	(0.0319)	(0.0352)	(0.0364)
	Maritime Distance 2§	-0.0576***	-0.0574***	-0.0573***	-0.0568***
	(d_{ij3}, Intermediate – U.S. Port of Entry)	(0.0037)	(0.0037)	(0.0050)	(0.0050)
Perceived Risk	Route Risk§	-0.1357***	-0.0893***	-0.1105***	-0.0264**
		(0.0089)	(0.0088)	(0.0090)	(0.0080)
	Route Risk × Unit Value		-0.0059***		-0.0091***
			(0.0009)		(0.0008)
Alternative-Specific Controls (Interacted with distances)	Landside Distance × Transshipping			-0.1011***	-0.0999***
	(Transshipping – 1: Yes, 0: No)			(0.0056)	(0.0056)
	Landside Distance			-0.3855***	-0.3298***
	× Panama-Crossing (W) (1: Yes, 0: No)			(0.0296)	(0.0315)
	Landside Distance			-0.4853***	-0.7104***
	× Panama-Crossing (E) (1: Yes, 0: No)			(0.0542)	(0.0562)
Shipment-Specific Controls (Interacted with distances)	Landside Distance × Shipper Size			0.0001***	0.0001***
				(0.0000)	(0.0000)
	Landside Distance × Unit Value			0.0216***	0.0285***
				(0.0009)	(0.0010)
	Maritime Distance 1 × Unit Value			-0.0015**	-0.0015**
	(d_{j2}, Forwarding – Intermediate Port)			(0.0005)	(0.0005)
	Maritime Distance 2 × Unit Value			0.0016**	0.0014*
				(0.0006)	(0.0006)
	Landside Distance × Shipping Volume			-0.0443***	-0.0469***
				(0.0025)	(0.0027)
	Maritime Distance 1 × Shipping Volume			0.0003	0.0003
				(0.0006)	(0.0006)
	Maritime Distance 2 × Shipping Volume			0.0000	0.0000
				(0.0008)	(0.0008)
	Alternative-Specific Fixed Effects	Yes	Yes	Yes	Yes
	AIC	83265.088	83165.139	80355.436	80160.618
	Log Likelihood	-41582.544	-41531.570	-40117.718	-40019.309
	McFadden's Pseudo-R^2	0.1913	0.1923	0.2198	0.2217
	Number of Observations	26109	26109	26109	26109
	Number of Alternatives	45	45	45	45

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; § Random coefficients; Standard errors in parentheses.

On average, a shipment is found to avoid a port pair and the associated shipping route whose landside segment is exposed to higher risk of armed violence. Coefficients of the landside route risk are in the range of -0.03 to -0.14 across models. These estimates show a highly significant and sizable effect of the landside route risk on the routing choice of shipments. Column 4 in Table 3-1 shows that one additional death per 100km from domestic armed conflicts along a landside shipping route diminishes the odds of choosing the associated port pair by 2.61% ($e^{-0.0967} - 1 = -2.61\%$). Furthermore, the route risk term interacted with unit value captures an additional route risk effect that is dependent on the unit value of the shipment; I find here how shippers respond to exposure to risk according to the value of shipped cargos. The negative sign of the coefficients in columns 2 and 4 confirms that freight of higher value is more likely to be routed away from higher risk landside routes. If the value of freight is $1 per kg higher, there is additional deterrence to use a high-risk route. Specifically, the odds of choosing a certain port pair contract by 0.91 % ($e^{-0.0091} - 1 = -0.91\%$) in favor of another that entails a less hazardous route. Thus, shipments with higher value are more averse to armed violence risk *en route* to their forwarding port.

These results strongly confirm the detrimental consequences of the inability of institutions to control civil conflicts in commercial terms, especially in the context of international freight shipping. This certainly further validates other studies that have focused on the heightened shipping cost of passing through the waters of Somalia due to frequent piracy activities (Besley *et al.* 2015) and the shipping behaviors deterred by bribery corruption at ports of South Africa (Sequeira and Djankov 2014), as well as the increasing costs of cargo theft on the economy of São Paulo (Justus *et al.* 2018).

Using the model specification of Equation (3-9) for subsets of the shipping data with different categories of HS commodity codes, I check if the exposure to violence risk has a differential effect across commodity types (Table 3-2). The analysis confirms that route risk, in general, has a negative impact on the movement of shipments by rerouting to

Table 3-2 Port pair choices and perceived risk across commodity types: Mixed logit model results

	(1) A Fresh Fruits & Vegetables	(2) B Processed Foods	(3) C Mineral Products	(4) D Metallic Raw Materials	(5) E Textile & Clothing	(6) F Light Manufacturing	(7) G Machinery & Mechanical	(8) H Chemicals
Landside Distance§	-1.1841^{***}	-1.7044^{***}	-1.5739	-4.1292^{***}	-2.7809^{***}	-2.5593^{***}	-3.4972^{***}	-3.2125^{***}
(d_{ij1}, Origin – Forwarding Port)	(0.0967)	(0.0934)	(0.9158)	(0.1566)	(0.2193)	(0.0702)	(0.4113)	(0.3157)
Maritime Distance 2§	-0.0205	-0.0736^{***}	0.1673	-0.0391	-0.0500	-0.0300^{**}	-0.0198	-0.0493
(d_{ij3}, Intermediate – U.S. Port of Entry)	(0.0140)	(0.0147)	(0.1423)	(0.0283)	(0.0335)	(0.0102)	(0.0238)	(0.0422)
Route Risk§	0.1956^{***}	-0.0204	-0.9582	0.0468	-0.0323	-0.1461^{***}	0.0192	-0.0053
	(0.0211)	(0.0194)	(1.1216)	(0.0530)	(0.0528)	(0.0166)	(0.0538)	(0.0426)
Route Risk × Unit Value	-0.1538^{***}	-0.0003	-0.1157	-0.0140	-0.0083^{**}	-0.0073^{**}	-0.0001	-0.0018
	(0.0172)	(0.0030)	(1.3210)	(0.0088)	(0.0031)	(0.0023)	(0.0023)	(0.0045)
Alternative-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alternative-Specific Control (Interacted with distances)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shipment-Specific Control (Interacted with distances)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AIC	19118.2254	11400.7023	452.9127	3081.9684	4094.8164	24120.6729	2723.5349	1640.7495
Log Likelihood	-9507.1127	-5653.3511	-199.4563	-1500.9842	-2015.4082	-12014.3364	-1323.7674	-785.3747
McFadden's Pseudo-R^2	0.2279	0.2366	0.4324	0.4735	0.3719	0.2161	0.2429	0.4159
Number of Observations	5067	3329	239	1909	2777	10471	1126	877
Number of Alternatives	36	31	11	24	16	30	22	19

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; § Random coefficients; Standard errors in parentheses.

another forwarding port along a safer route. Also, I find that the magnitude and statistical significance of these effects vary by commodity type and shipment unit value. The baseline route risk has a strongly negative effect on shipments of light manufacturing products (F); the effect is not statistically significant at 5% for the other commodity types, except fresh fruits and vegetables (A). The additional effects of the route risk by shipment unit value are also found to vary across commodity types. The baseline effect on shipments of fresh fruits and vegetables (A) is shown to have a positive effect, but the total effect becomes negative just if the unit value of products is more than \$1.27 per kg. Even though the baseline route risk has no statistical significance at the 5% level for shipments of textile and clothing products (E), the total risk effect is negative and stronger as more expensive products are shipped. The route risk effect is invariant with unit value when shipping other commodity types at the 5% significance level. I will discuss the heterogeneity in the risk effect across commodity type in more detail later.

3.4.2. Risk-to-Distance Equivalence

I quantify the price of the state's failure to control domestic armed conflicts on freight mobility by estimating the shipping distance equivalence of the additional risk of armed violence along landside shipping routes. As indicated earlier, the magnitude of the route risk can be measured with landside and maritime distance terms by using the random coefficients estimated in the mixed logit model. The landside and maritime RDEs are estimated based on the model specification given in Equations 3-11, 3-13, and 3-14. For comparison between the landside and maritime RDEs, I consider different scales of landside and maritime shipping distances and unit freight costs. I compute maritime RDEs converted to the landside distance scale by multiplying the maritime RDEs by a proportion of maritime to landside trucking unit freight cost ($ per km-ton). I take the 2012 landside unit freight cost data estimated by the Colombia Ministry of Transport (2012)[2]. The maritime unit freight cost data are taken from Vega *et al*. (2019). The average landside and maritime unit freight rates are computed by averaging pairwise landside freight rates by summing the landside shipping distances and pairwise maritime freight rates from Colombian ports to Los Angeles as the sum of maritime shipping distances, respectively. By doing so, I obtain a conversion factor of 0.102.

Given the sensitivity of route and port choices detected for different commodity types, my approach consists in segmenting the shipping data according to the commodity types used earlier to allow for the associated variation of risk-to-distance equivalence. Estimated RDEs are reported in Table 3-A4 and Figure 3-6. The analysis shows that the violence risk along landside routes significantly degrades freight mobility of the majority of exported products (positive RDE), but the effect is not necessarily consistent across commodity types. The RDEs estimated for shipments of all commodity types indicates that an additional death per 100 km is equivalent to extending the landside shipping distance by 6.178 km and the maritime shipping distance by 233.619 km (or 23.845 km on the landside distance scale by conversion). If a product is shipped through a landside route with an average level of risk, that is 17.406 deaths per 100 km, it generates the same effect as an extension of the landside shipping route by 107.534 km and of the maritime shipping route by 4,066.372 km (or 415.038 km on the landside distance scale). This means that higher risk of armed violence along shipping routes has the same effect on route and port

[2] 2012 is closest among available records to the time period of our shipping data.

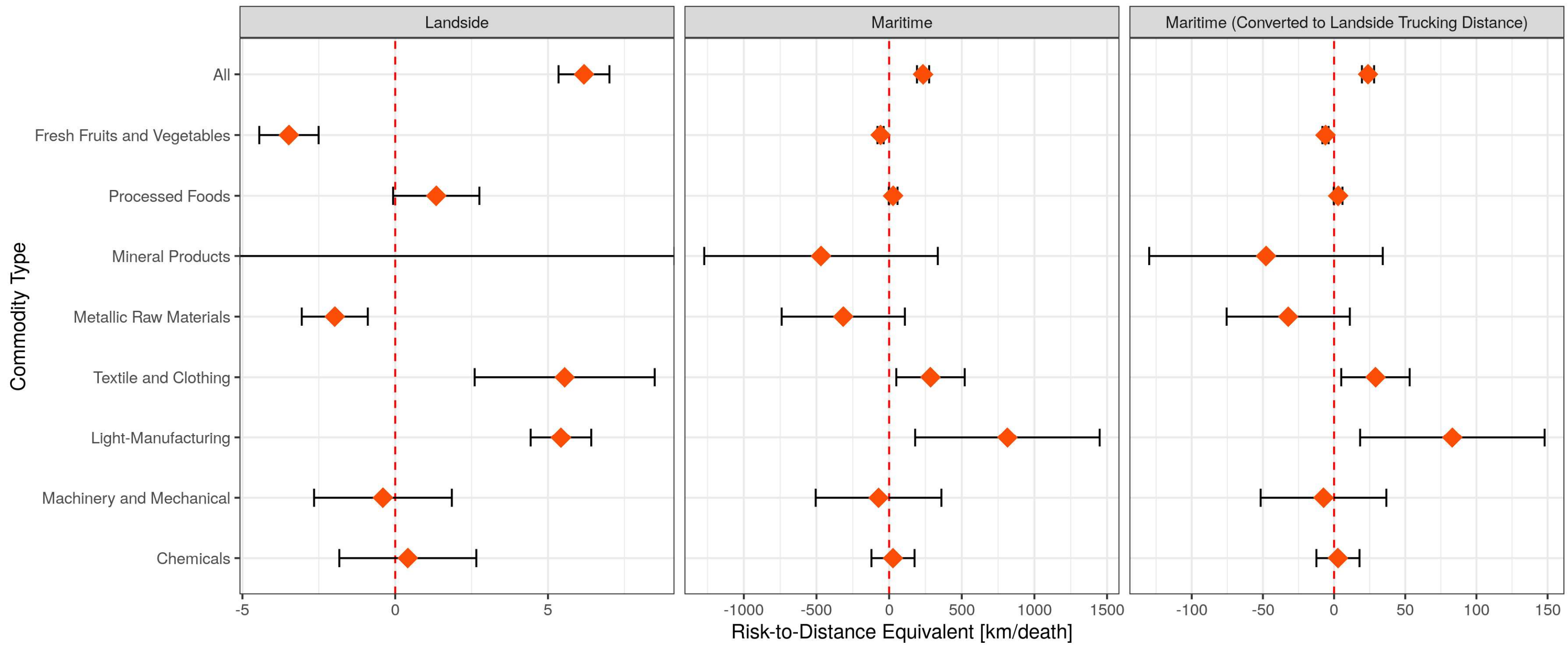

Figure 3-6 The landside and maritime risk-to-distance equivalences by commodity type (From Table 3-A4)
(Note: For comparison with the landside RDEs, the panel on the right-hand side reports the maritime RDEs converted to the landside distance scale, by multiplying them by 0.118, the average proportion of maritime to landside trucking unit freight cost ($ per km-ton). The unit freight cost data are taken from Colombia Ministry of Transport (2012) and Vega et al. (2019))

choice as extending both landside and maritime shipping distance and therefore the shipping costs. Shippers would trade-off a port reachable on a riskier route for ports located further away from the shipping origin, provided that the access route has lower risk. Also, they would be willing to take a safer landside shipping route to ports over a riskier one, even though the maritime segment of the associated shipping distance to the U.S. port of entry is quite extended. Logistically, the extension of the maritime shipping route by 4,066.372 km is equivalent to 415.038 km on the landside distance scale, indicating a greater sensitivity of shippers to armed violence risk on the maritime segment than on the landside segment.

However, the RDEs differ notably by commodity type. When shipping textile and clothing, and light manufacturing products, additional risk is found equivalent to a longer landside shipping distance. However, the 95% confidence intervals of the landside and maritime RDEs of processed foods, mineral products, machinery and mechanical products, and chemical products include zero, indicating the lack of statistical evidence that additional risk is equivalent to an extension of the landside and maritime shipping distance when these types of products are shipped. It is also notable that the 95% confidence interval of the landside and maritime RDEs of mineral products have a particularly wide range between -78.859 and 181.548 km and between -1,272.550 and 335.068 km, respectively, which points to the highly uncertain effect of violence risk on route and port choice for these products. It is possible that the product's origin is associated with the differential RDE across commodity type, and I will discuss this later in the analysis.

When shipping fresh fruits and vegetables and metallic raw materials, the landside RDE is found negative, indicating that their shipments are more sensitive to landside distance than to the risk of armed violence on the route. As for the maritime RDE, it is found negative only when shipping fresh fruits and vegetables but not significant when shipping metallic raw materials. This means that, for shipments of fresh fruits, reducing both landside and maritime shipping distance is far more important than avoiding the route risk. Considering that fresh fruits and vegetables are perishable goods, it is more pressing to ship to closer forwarding ports and routes with a shorter maritime voyage to preserve the quality of products and reduce shipping cost, rather than following a longer but safer export route. For shipments of metallic raw materials, reducing landside shipping distance is found more important than avoiding the risk of violence, while shippers are rather indifferent between maritime shipping distance and route risk. Since metallic raw materials are heavy and are subject to a greater freight cost, the analysis indicates that shipments tend to take place to closer forwarding ports to reduce the landside shipping distance rather than avoid the route risk. However, such a tendency does not hold on to the maritime segment, possibly due to high efficiency in maritime shipping. I can find that, for shipments of metallic raw material, the coefficient of the landside distance is highest among all commodity types; however, the coefficient of the maritime distance is not significant at the 5% significance level, confirming the expensive landside shipping cost of metallic raw materials.

3.4.3. Heterogeneity in Risk Effect

The variance in RDEs across commodity types suggests that heterogeneity in the risk effect exists across shipments. To confirm the sources of this heterogeneity, I estimate how the variances in RDEs are explained by the unit value, commodity types of shipments and other shipment-specific characteristics. The following steps are used to this end. From the random coefficients estimated through the mixed logit model on the full dataset (Table 3-A4, column 1), I obtain shipment-specific landside RDE estimates by dividing the shipment-specific coefficient of the route risk by that of the landside shipping distance (Equation 3-13). I regress the shipment-specific RDE estimate on a number of hypothesized predictors, namely its unit value, commodity type dummy variables, shipment volume, shipper size and a dummy variable indicating whether the U.S. port of entry is on the West Coast, while controlling for the origin-specific fixed effects with origin municipality dummy variables. I proceed in the same way with the maritime RDE on the basis of Equation 3-14.

Table 3-3 reports that all the variables listed above contribute to the heterogeneity in the landside and maritime RDEs across shipments. It should be noted that the model includes origin-specific dummy variables to control the origin-specific fixed effects and the possible association between the product origin and the RDEs. The positive signs of the unit value coefficients confirm that shipments of higher value have higher RDEs, meaning that they are more likely to have their landside and maritime shipping distances extended to avoid insecurity and potential risk along landside shipping routes. While larger-volume shipments are found to have lower landside and maritime RDEs and, therefore, to be more sensitive to risk, larger shippers tend to have higher RDEs and to be more sensitive to risk. Freight shipped to the U.S. West Coast is found to have a lower landside RDE but a higher maritime RDE than those to the U.S. East Coast. Since all commodity type dummy variables of the result on the landside RDE are statistically significant, I can also confirm that the mean landside RDEs are statistically different across commodity types at the 99% significance level. Even though the maritime RDEs of only

Table 3-3 Heterogeneity in individual risk-to-distance equivalent estimates

	(1) Landside RDE	(2) Maritime RDE
Intercept	7.4654***	243.9149***
	(0.2926)	(11.3235)
Unit Value	0.0142***	0.7116***
	(0.0021)	(0.0822)
Shipment Volume	-0.0193***	-0.6486***
	(0.0015)	(0.0589)
Shipper Size	0.0001***	0.0037***
	(0.0000)	(0.0003)
U.S. Port of Entry on the West Coast	-0.3929***	3.4096*
(1: Yes, 0: No)	(0.0404)	(1.5639)
Commodity: B. Processed Foods	-0.2317***	-19.3639***
(1: Yes, 0: No)	(0.0470)	(1.8203)
Commodity: C. Mineral Products	0.7628***	5.0838
(1: Yes, 0: No)	(0.1286)	(4.9773)
Commodity: D. Metallic Raw Materials	0.5239***	1.8247
(1: Yes, 0: No)	(0.0543)	(2.1014)
Commodity: E. Textile and Clothing	0.7366***	6.0476**
(1: Yes, 0: No)	(0.0558)	(2.1607)
Commodity: F. Light-Manufacturing	0.5337***	-4.5778***
(1: Yes, 0: No)	(0.0351)	(1.3601)
Commodity: G. Machinery & Mechanical	0.5421***	-3.4916
(1: Yes, 0: No)	(0.0672)	(2.5998)
Commodity: H. Chemical Products	0.8894***	16.1218***
(1: Yes, 0: No)	(0.0735)	(2.8449)
Commodity: O. Miscellaneous	0.4550	4.0820
(1: Yes, 0: No)	(0.3004)	(11.6270)
Origin-Specific Fixed Effects	Yes	Yes
Adjusted R^2	0.1896	0.1602
Number of Observations	26109	26109

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; Standard errors in parentheses. The baseline category of commodity types is A. Fresh Fruits and Vegetables.

processed foods, textile and clothing, light manufacturing, and chemical products are statistically different from that of fresh fruits and vegetables, there is still significant heterogeneity in the maritime RDE across commodity types. These two results show that the effect of the commodity type accounts for a substantial part of the variance in individual RDEs, even when the unit value is controlled for.

Various estimation results in Tables 3-1, 3-2, 3-3, and Figure 6 consistently confirm that the route risk effect and RDEs are heterogeneous across commodity types. These results imply that shippers may have different shipping behaviors in response to potential risk along the landside routes. I can provide several reasons for this. First, certain products can easily be reproduced and replaced when they are damaged or lost, or the shipment is disrupted. In this case, shippers may choose to ship through shorter routes, even if riskier, rather than pay more freight costs by taking safer but extended shipping routes. In this respect, fresh fruits and vegetables have negative landside and maritime RDEs, metallic raw materials have negative landside RDEs, and processed foods have lower landside and maritime RDEs than textile and clothing, and light manufacturing products do. Given that it takes relatively longer to reproduce textile and clothing and light-manufacturing products once they are lost, I argue the difference in RDE values may be explained by such considerations.

Second, the shipping of certain commodities may exhibit inflexibilities that severely constrain the choice of ports and of the associated landside shipping route to them. If a product is more susceptible to shipping delays on alternate shipping routes, hauling through the least-cost port may be the preferred option, even if the risk of potential disruption along this route is high. On a similar note, a product that requires specialized handling facilities and storage at the forwarding port may be captive to ports that have such facilities, therefore being unable to switch to another port in spite of the risk differential. For instance, metallic raw materials are shown to have a negative landside RDE, while the maritime RDE is not statistically significant at 5%. Shipments of metallic raw materials may not be flexible against the risk because the shipments require specialized logistic and storage facilities and are expensive due to their heavy weight, as indicated by the higher value of the landside distance coefficient (Table 3-2, column 4). Also, I see that fresh fruits and vegetables have negative landside and maritime RDEs, while processed foods have the second smallest RDE among all commodity types with positive RDEs. Given that food products are perishable and that freshness is the highest priority in shipping, shippers may prefer to avoid taking extended landside shipping routes to arrive at port facilities without delay, even if this means following a riskier route. In contrast, the shipment of other non-perishable and durable goods may have more flexible shipping schedules, which makes it more possible to avoid risks of violence and cargo loss along shorter routes.

Third, outlaw groups may show discriminatory behavior in their actions towards freight trucks in the territories they control. They may target trucks that potentially bring them more financial benefit. They could target only freight that is easily transferrable for their own use, that is more durable so that value is maintained high enough for market resale, or for which they can charge higher bribery or tolls from shippers or shipping companies. Sierra (2013) mentioned that electronics, electrical appliances, and textiles are most likely subject to theft along the shipping corridors in Colombia. In Aceh, Indonesia, corrupted officials showed discriminatory behaviors in charging bribery payment to trucks at checkpoints for passage, and the payment was higher for higher-value cargo, higher for steel, and lower for processed goods (Olken and Barron 2009).

In a similar but different context, Ibáñez and Vélez (2008) found that Colombian rebel groups are more likely to victimize and force civilians whom they can easily prey upon, such as landowners, young individuals and households with lower economic privileges. If this is the case also in shipping textile and light manufacturing products would indicate that illegal groups prefer targeting and extorting shippers of those products due to higher expected profit from market resale, bribery, and tolls. This is quite probable since these products are non-perishable and durable, so they undergo less depreciation for market resale than other products. It is notable that larger shippers tend to have higher RDEs (Table 3-3), indicating that they are more sensitive to risk and more likely to follow longer landside shipping routes. It is highly likely that illegal groups expect higher value of bribery or tolls from a larger shipper than a smaller one and that a larger shipper's freight would be a more tempting target to them. The positive sign of the shipper size coefficient in Table 3-3 may therefore reflect that shippers adjust their route choices against outlaw groups' discriminatory actions towards shipments of larger shippers. This implies that shippers are impacted differently by the risk of the route to ports and therefore respond by adjusting their freight mobility choices differently according to the type of commodity being exported and to shipper size.

3.5. Conclusions

As international freight transportation becomes unprecedently more inexpensive and faster than ever, the frictionless and seamless flow of commerce has been regarded as axiomatic and infallible. It has been taken for granted that the global logistic chain is operated with full security anywhere, and the disruption of international freight shipping has been out of one's mind. My study posits that failure to control armed violence along trade routes severely impedes freight shipping, increases the cost of doing business, and greatly limits access to the global market, potentially discouraging export-oriented economic activities.

I focused on the case of Colombia in 2006-2007, when state failure led to frequent domestic armed conflicts between insurgents, paramilitary groups, and government forces, to show how exposure to risk is a heavy tax on freight shipping. Colombia is widely known as a country whose economic growth has been impeded by the state failure of its state institutions and by frequent violence, and this paper presented that the country's freight shipping system has been severely affected. Through micro-level analysis matching bills of lading records from PIERS and georeferenced domestic armed conflict data from UCDP, I found strong evidence from Colombia in a period of heightened political violence in 2006-2007 that risk of violence along landside shipping routes results in altered geography of freight mobility, with least-cost ports and landside access corridor being avoided in favor of other, safer options. My mixed logit modeling results suggest that more exposure to risk along trade routes has a negative effect on the odds of choosing pairs of forwarding and intermediate ports on the way to foreign markets. The average level of violence along landside trade routes (17.406 deaths per 100 km) is estimated to be a 105.823 km and 4,066.372 km extension of the landside and maritime shipping distance, respectively. This points to the rerouting of shipments to further ports to avoid armed violence risk and the consequent rise in impediments to freight mobility. I also confirmed that the effect of risk of armed violence varies across shipping instances. All other things being equal, shipments tend to reroute further in response to risk when textile and clothing, light-manufacturing products, and higher-value products are shipped, or when shipments originate from larger shippers. The heterogeneity in the risk effect implies that guerrilla rebel groups or paramilitary groups exhibit discriminatory behaviors vis-a-vis shipments passing through their territories, and that shipments have different levels of flexibility in changing routes against risk.

My study points to important implications in terms of interregional and international trade-oriented development policies. First, it is important for countries to design and implement policies to guarantee full security in any segments of trade routes and provide a secure environment for freight transportation. Only in the absence of concern about potential death threats, blockade, and extortion of tolls, will shippers be able to make effective decisions to minimize their freight shipping cost for interregional and international export activities and only then can efficient operation of freight transportation systems be achieved. Along this line of thought, it would be useful for future research to assess the economic impact of restricted freight mobility and calculate the welfare lost by the route change forced by the political instability on municipalities, especially port areas like Buenaventura.

Second, disruptions in any segment of the trade routes can be a great cost for freight haulage; hence, efforts from trading partners to control domestic armed violence is a key to lowering the friction of commodity flows and to increasing the mutual benefit from trade. Promoting frictionless bilateral trade flow is not just a matter of economic and diplomatic relationships between trading partners, but also of how they establish a stable domestic geopolitical environment and maintain security in freight transportation without undue disruption. Thus, international cooperation is necessary to maintain the efficient operation of the logistic chain system.

Third, investment in supply chain infrastructure should be made with careful consideration of geopolitical environments to guarantee the full security of freight transportation. Foreign aid programs to developing countries have largely focused on investment in improving road and rail infrastructure and port systems without appropriate consideration for the lack of institutions to control internal violence and its potential impact on efficient operation of the transportation systems (Ali *et al.* 2015). No matter how considerable are the resources invested in supply chain infrastructure to promote access to global markets, such financial support can readily be offset by disruptions to cargo flows by violence in developing countries without proper institutions. Foreign aid support for transportation development should be accompanied by appropriate measures and dispositions to remedy political instability.

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APPENDIX: SUPPLEMENTARY TABLES

Table 3-A1 Terrain slope's influence on speed and impedance factor to distance (Source: Tao *et al*. (2016, p. 418))

Slope (degree)	Difficulty	Slope's Impact on Travel Speed	Impedance Factor to Distance
< 5	Easy	100%	× 1
5 – 10	Moderate	50%	× 2
10 – 20	Hard	20%	× 5
20 – 40	Difficult	10%	× 10
> 40	No-go	0%	× ∞

Table 3-A2 Classification of commodity types

Class	Label	First 2-digit HS Code
A	Fresh Fruits and Vegetables	06, 07, 08, 09, 10, 11, 12, 13, 14
B	Manufactured Agricultural and Animal Products	01, 02, 03, 04, 05, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24
C	Mineral Products	25, 26
D	Metallic Raw Material	72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 83
E	Textile and Clothing	41, 42, 43, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67
F	Light Manufacturing Products	39, 40, 44, 45, 46, 47, 48, 49, 68, 69, 70, 71, 82, 94, 95, 96, 97
G	Machinery and Mechanical Products	84, 85, 86, 87, 88, 89, 90, 91, 92, 93
H	Chemical Products	28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38
O	Petroleum Oil	27
Z	Miscellaneous Products	00, 98, 99

Table 3-A3 Descriptive statistics

Variable	Unit	Mean	Standard Deviation	Min	Max
Landside Distance, d_{ij1} (Origin – Forwarding Port)	100 km	6.779	3.498	0.078	20.113
Maritime Distance 1, d_{j2} (Forwarding – Intermediate Port)	100 km	19.465	15.828	0	64.636
Maritime Distance 2, d_{ij3} (Intermediate – U.S. Port of Entry)	100 km	37.385	21.069	2.046	139.606
Route Risk	Death / 100 km	17.406	9.176	0	89.281
Unit Value	USD / kg	4.208	7.345	0	134.231
Shipment Volume	Twenty-foot Equivalent Units	2.975	9.183	0	210
Shipper Size	Twenty-foot Equivalent Units	1,251.44	2,085.36	0.01	13,622.64
Port Throughput (Forwarding ports)	Twenty-foot Equivalent Units	17,668.87	11,780.41	60.36	37,654.24
Port Throughput (Intermediate ports)	Twenty-foot Equivalent Units	4,240.50	7,260.14	1.13	26,604.57
Transshipping	Dummy variable (1: Yes, 0: No)	0.133	0.340	0	1
Panama-Crossing (Westward)	Dummy variable (1: Yes, 0: No)	0.068	0.251	0	1
Panama-Crossing (Eastward)	Dummy variable (1: Yes, 0: No)	0.318	0.466	0	1

Notes: Sample includes 1,174,905 observations (= 26,109 × 45 [Bills of Lading × Alternatives])

Table 3-A4 Estimation of the risk-to-distance equivalence across commodity types

	(1) All	(2) A Fresh Fruits & Vegetables	(3) B Processed Foods	(4) C Mineral Products	(5) D Metallic Raw Material	(6) E Textile & Clothing	(7) F Light-Manufacturing	(8) G Machinery & Mechanical	(9) H Chemicals
Mean Landside RDE [km]	6.1784	-3.4777	1.3429	51.3445	-1.9776	5.5463	5.4244	-0.4009	0.4126
2.5% Percentile	5.3457	-4.4486	-0.0690	-78.8593	-3.0583	2.6002	4.4333	-2.6550	-1.8293
97.5% Percentile	7.0111	-2.5067	2.7548	181.5483	-0.8969	8.4925	6.4155	1.8532	2.6545
Mean Maritime RDE [km]	233.6189	-58.9562	27.8119	-468.7412	-315.5131	284.8190	814.1510	-72.7627	26.6743
2.5% Percentile	191.7749	-80.3982	-2.2044	-1272.5501	-739.4648	49.3665	179.1762	-505.3321	-121.6863
97.5% Percentile	275.4630	-37.5143	57.8282	335.0678	108.4386	520.2715	1449.1258	359.8067	175.0349
Mean Maritime RDE# [km]	23.8445	-6.0174	2.8386	-47.8425	-32.2031	29.0703	83.0971	-7.4266	2.7225
2.5% Percentile	19.5737	-8.2059	-0.2250	-129.8840	-75.4742	5.0386	18.2878	-51.5772	-12.4200
97.5% Percentile	28.1154	-3.8289	5.9023	34.1990	11.0679	53.1020	147.9064	36.7240	17.8651
Landside Distance§	-2.1928***	-1.3281***	-1.7532***	-2.4028	-4.4086***	-2.8246***	-2.8627***	-3.6484***	-3.6398***
(d_{ij1}, Origin – Forwarding Port)	(0.0311)	(0.0425)	(0.0688)	(2.1433)	(0.1036)	(0.1698)	(0.0694)	(0.3262)	(0.3348)
Maritime Distance 2	-0.0580***	-0.0783***	-0.0847***	0.2632*	-0.0276	-0.0550**	-0.0191**	-0.0201	-0.0563
(d_{ij3}, Intermediate – U.S. Port of Entry)	(0.0037)	(0.0077)	(0.0095)	(0.1122)	(0.0170)	(0.0202)	(0.0074)	(0.0172)	(0.0327)
Route Risk§	-0.1355***	0.0462***	-0.0235	-1.2337	0.0872***	-0.1567***	-0.1553***	0.0146	-0.0150
	(0.0088)	(0.0072)	(0.0125)	(1.0541)	(0.0252)	(0.0356)	(0.0134)	(0.0427)	(0.0407)
Alternative-Specific Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alternative-Specific Control (Interacted with distances)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shipment-Specific Control† (Interacted with distances)	Yes†	Yes†	Yes†	Yes†	Yes†	Yes†	Yes†	Yes†	Yes†
AIC	83012.7322	20619.9076	11570.7480	497.8945	3178.9743	4181.2498	24634.1743	2790.8262	1658.9673
Log Likelihood	-41454.3661	-10266.9538	-5747.3740	-230.9472	-1558.4872	-2067.6249	-12280.0872	-1366.4131	-803.4836
McFadden's Pseudo R^2	0.1938	0.1661	0.2239	0.3428	0.4534	0.3557	0.1988	0.2186	0.4024
Number of Observations	26109	5067	3329	239	1909	2777	10471	1126	877
Number of Alternatives	45	36	31	11	24	16	30	22	19

Notes: *** $p < 0.1\%$; ** $p < 1\%$; * $p < 5\%$; § Random coefficients; † Include shipment-specific controls interacted only with maritime distance 1 (d_{j2}, Forwarding–Intermediate Ports); # (Note: For comparison with the landside RDEs, the maritime RDEs and their 95% confidence intervals are converted to the landside distance scale, by multiplying them by 0.118, the average proportion of maritime to landside trucking unit freight cost ($ per km-ton). The unit freight cost data are taken from Colombia Ministry of Transport (2012) and Vega et al. (2019); Standard errors in parentheses; The standard errors and 95% confidence intervals of the RDEs are estimated with the delta method.

CONCLUSIONS

By many accounts, the modern international freight transportation system has dramatically reduced physical, socioeconomic and technological barriers to commercial activities. The reduced barriers have made any local commercial activities, which are believed to be independent of the global economy, captive to the global supply chain and have brought them under the influence of the global economy. This change has shifted the geographical fundamentals on how we define spatial organization, spatial economic interaction and freight mobility in the global economic space. In this dissertation, I studied three main pillars of the modern international freight transportation system that govern international commercial activities: intermodal logistic integration, the hub-and-spoke distribution system and logistic chain security.

By scrutinizing the three elements of the modern international freight transportation system, my studies filled the knowledge gap that exists in the literature of economic geography. My first study examined how sea-land intermodal logistic integration shapes the spatial structure of the port system. Even though landside and seaside transportation flows are now integrated by sea-land intermodal logistic integration, like containerization and hub-and-spoke distribution system, previous studies have examined either landside or seaside flows separately to delimit the spatial structure of the port system and have presented a limited view only. Based on network analysis models of disaggregated shipment flows across land and sea, the results confirmed that a hinterland area is not just limited by the local vicinity of ports, but a group of hinterlands, forelands and ports exist interdependently as a continuum, not separate entities.

The second research dealt with a central pillar of modern international freight transportation, namely the hub-and-spoke distribution system. In previous studies, there was rare empirical evidence on how a hub-and-spoke distribution system specifically reduces distance friction along the route and contributes to the global shrinkage in space. By examining routing behaviors of disaggregated shipment records from Europe to the U.S., I studied how the hub-and-spoke distribution system reduces the distance friction on shipment flows and how it explains global shrinkage in space. I found that scales of the port operations and shipping line diversity at traversed ports along the route are main drivers that generate hub-and-spoke shipping (dis)economies and that the configuration of the hub-and-spoke distribution system can reduce distance friction on shipping flow.

The final piece of research investigated the relationship between supply chain security and freight mobility. Complete security has been considered an endowed condition everywhere for modern long-distance commerce, but it is little known how shipping flow is impeded when security is compromised. I focused on cases of Colombia, where shipment flows are often obstructed by rampant domestic armed conflicts along trade corridors to ports, to examine the effect of insecurity on freight mobility. I analyzed choice behaviors in shipment routing with different levels of risk to examine if and how freight mobility is compromised by the lack of insecurity along the route. The results present that shipping flows are greatly re-routed to further ports to avoid domestic armed violence along inland corridors.

By examining different aspects, my studies gave theoretical, methodological and policy contributions to the understanding of spatial interaction dynamics of long-distance commerce. First, I found that mechanisms of spatial interaction of long-distance commerce, which was once considered to be under the absolute power of distance, should now be reestablished in consideration of the trade logistic process from location to location. Certainly, distance remains a meaningful factor in describing the spatial organization of the port system, shipping flow patterns and freight mobility. However, my research found that intermodal logistic integration, hub-and-spoke distribution system and supply chain security are more important key components of the modern international transportation system that determine the global spatial organization, shipping flow and freight mobility than distance.

Second, the adoption of various quantitative modeling approaches better elucidates complex patterns of shipping flows from location to location. I found that spatial interaction of long-distance commerce cannot be described by a simple gravity equation and distance decay specification. Application of network analysis and of mixed logit models to micro-level shipment records helped to trace shipping flow patterns across land and water and characterize the effects of the hub-and-spoke configuration and of insecurity along trade routes. By doing so, I was able to capture the “dark” distance factors like intermodal logistic integration, hub-and-spoke distribution systems and supply chain security that have been glossed over in previous studies. This will provide new methodological guideline for future research on modeling spatial interaction of long-distance commerce in the context of modern international freight transportation.

Last but not least, the findings highlight the importance of considering the elements of the contemporary international transportation system in port-driven transportation development or export-oriented economic development policies. When promoting a port-driven regional development, it becomes more essential to be aware of the geographical scope of both landside and seaside shipment flows from and to ports and consider hub-and-spoke configurations along the route their shipments would traverse. If a country pursues investment in transportation infrastructure to improve freight mobility, it is imperative to consider a potential consequence of lacking supply chain security along the trade route and consider a policy measure to accommodate supply chain security to prevent failure of the infrastructure investment.

Despite the contributions of my research, I acknowledge a few limitations. First, my research did not use a detailed trajectory of the shipments' actual movement, and the analyses are only based on the intermittent locations of traversed ports along the route throughout the three studies. Due to data limitation, there was no way to get the actual movement trajectory and shipping distance, so the modeling should be based upon some assumptions, like the shortest-path distances and mode of inland transportation. Especially, I could not track shipments down to the final destination and foreland-side shipping trajectory over the U.S. ports of entry. The spatial interaction dynamics could be more precisely described, but this was the best approximation to the reality that I could do with the limited information about the movement trajectory.

Second, my studies did not focus on a logistic chain of a particular type of commodities but only analyzed a general pattern of containerized shipments. Considering that a transportation system is closely tied to local business activities and industries, it could be developed differently to specialize in shipments of local products and of a particular type of commodities. It is possible that spatial structures of the port system, distance friction, sensitivity to risk and logistic chain security would vary by main commodity types.

Third, the studies were cross-sectional and could not examine longitudinal change in spatial interaction dynamics of long-distance shipments. Production and transportation of commodities is rather seasonal and change with the global demand and supply across years. The time period of the studies was limited to the late 2000s, and I could not track how spatial interaction dynamics have changed after that. Especially, the change after the Global Financial Crisis could not be captured, which is a main limitation of the research.

Based on these limitations, I can envisage several directions for future research. First, it would be interesting if a future study focuses on the logistic chain of a certain type of commodities and examines the relationship with local businesses and socioeconomic environments. For example, one may focus on shipments of coffee or agricultural products in Colombia and examine the relationship between commodity-specific logistic chain, local commerce and illegal activities and domestic armed violence. Second, a study using multilayers of shipment-related datasets would be promising. Combining PIERS, the automatic identification system (AIS) data and with detailed vessel trajectory, and satellite image data on vessels would provide information about unobserved features of the logistic process along the route, and then I can better understand detailed spatial interaction dynamics of long-distance shipments. Third, with shipment records across multiple years, it is possible to study the structural change in shipping patterns before and after a sudden socioeconomic event, like the Global Financial Crisis, economic sanction, war, battle, Brexit and free trade agreement between countries.