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Global Shrinkage of Space and the Hub-and-Spoke System in the Global Trade Network

Paul H. Jung[1,2] ·Jean-Claude Thill[3,4]

Abstract

We explore how the hub-and-spoke system in the international freight 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 is mitigated by the quality of scale economies driven by the hub-and-spoke distribution system along the trajectory of the logistic process. In order to confirm the shrinkage of space brought about by the hub-and-spoke shipping economies through transshipment routes via hub ports, we examine disaggregated cross-Atlantic cargo shipping trajectory data from Europe to the U.S. recorded both on landside and seaside with a discrete choice model. The results present that hub-and-spoke shipping economies arise with the scales of landside and maritime port operations and with shipping line diversity. Generally, they are found to offset distance friction that occurs along landside and maritime shipping voyages, but hub-and-spoke shipping economies arise differently depending on how hub-and-spoke configurations are set. They mainly stem from larger scale of ports' operation and more diverse shipping lines serving the final port of export. The hub-and-spoke system is confirmed as a main driver of global shrinkage of space in terms of long-distance commercial activities.

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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.* 2002, 2007, Buch *et al.* 2004, Glaeser and Kohlhase 2004, Knowles 2006, Hummels 2007, Bleaney and Neaves 2013, Lendle *et al.* 2016). 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 (Rietveld and Vickerman 2004, Carrère and Schiff 2005) and even has increased over time (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, we 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 (Janelle and Beuthe 1997, Hummels and Skiba 2002, Knowles 2006, Hesse 2013). The majority of trade shipments arriving at U.S. ports are found to be indirectly shipped through a small number of hub ports where transshipment activities are concentrated (Ganapati *et al.* 2021). The global port system is characterized by a hierarchical structure where a few hub ports with advanced capacity for maritime shipping dominate (Wang and Wang 2011). Since the higher transport density of inter-hub trunk lines results in more intensive use of port facilities, containers and shipping services, scale economies or density economies arise and the unit shipping cost declines (Mori and Nishikimi 2002, Mori 2012, Xu and Itoh 2017).

Knowles (2006) argued that time- or cost-space convergence is not monotonic, but instead it is 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 low 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 (Plane 1984, 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, we 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, we 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 trading regions? 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, we 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 trade routes. We especially consider how transshipment and hub-and-spoke configurations alter the generalized cost of shipping and affect decisions of shipping parties on the route choice for long-distance commerce. Our 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, we 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., we track how freight shipping routes are differentiated, as they span from the geographic source of shipments, to intermediate ports, and then to the U.S. ports 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. By tracing the trajectory patterns along the sequence of ports, we can identify the differential impact of the friction of distance in relation to hub-and-spoke configurations. We 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 each route. We demonstrate that the generalized cost of shipping is diminished when they are processed through a route that exhibits the characteristic traits of a 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. Using micro-level data provides advantages vis-à-vis aggregated trade shipment data in characterizing hub-and-spoke configurations of each route, in identifying their effects in each shipment and in exhibiting how distance friction is offset by the hub-and-spoke distribution system.

We first review two strands of the literature pertaining to this research. Then we 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.

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, we review the theoretical background of each strand and synthesize it to draw our hypothesis that the hub-and-spoke freight distribution system weakens the distance friction effect on trade flows.

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 (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 flows (Bergstrand 1985, Buch *et al.* 2004, Coe *et al.* 2007, Gallego *et al.* 2015). 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 (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.

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 (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 a differential collapse in space. For example, Kuby and Reid (1992) found that the technological advances driven by the containerization from 1970 to 1988 resulted in the concentration of cargo handling and liner shipping into fewer ports, implying tendency toward the hub-and-spoke network with transshipment hubs. 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 the concentration of freight shipping to a larger but farther hub port because of cheaper transportation cost than a smaller nearby Japanese hub. Ganapati et al. (2021) found that the majority of trade destined to U.S. ports are shipped through a small number of hub ports where a large volume of indirect shipments is concentrated. Their analysis found that the concentration of shipments to those hub ports resulted in lower transport costs brought by scale economies and the formation of larger hubs. 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).

Synthesis and Hypotheses

How much does geographic distance still matter in bilateral international trade? If the hub-and-spoke configuration of shipping systems has contributed to economic globalization, does the distance friction decline when shipping takes routes through hub ports? How can we 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 a 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 means of the reduction in the friction of distance.

In order to substantiate the distance convergence and settle the so-called distance puzzle, we adopt a discrete choice modeling framework that empirically compares 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.

Data and Variables

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 consistent 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 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 1). Basically, the last foreign ports of export in the PIERS are taken as P2. For P1, we take the so-called "pre-carrier[i]" city name in the PIERS dataset, provided that this city operates a commercial 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 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 U.S. (P1 = P2). For routes with transshipment (hereafter, referred to as TS routes), we 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, we 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 us 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, we 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 our 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 the purpose of this study. Accordingly, we use the following steps to filter out these bills of lading. We 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, we only retain shipments whose first and final ports are identified to process more than 10 shipments in our original 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.

Measurement of shipping distances

Given the specificities of the bill of lading dataset, we 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, we 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, we 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. We measure the shortest-path distances between the shipping source and the 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.

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, we 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), and intermediacy of nodes on the shipping route. We 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 from the scale of the ports (Figure 2-a). When a port is used heavily and its total throughput increases, the efficient use of shipping services and port facilities can generate scale economies and decrease the unit cost of inter-port freight shipping. A port's scale economies can effectively be approximated by some measurement of the size of the freight traffic handled. 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, we 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, we 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 shipments 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. We use the Shannon entropy index to quantify how diverse the shipping line services at a port are:

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

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 higher 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-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. The Shannon index is also measured on inbound maritime feeder lines from other ports (inbound feeder line diversity). 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, we 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 be transferred and, thus, work as a terminal where multiple shipping lines meet. For each route, we measure the intermediacy of the final port by the ratio of the direct maritime shipping distance between the shipment's P1 and PUS to the route's total maritime shipping distance (P1-P2-PUS). If the ratio is closer to 1, the route's total shipping distance is well approximated by the direct route, indicating that the final port is geographically close to an "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, meaning that transiting through the final port is a significant departure from the shortest path.

As presented in Figure 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, we 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. We 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 are reported in Table 1.

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Modeling Strategy

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, we 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 (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 exist.

We 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:

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

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} is a part explained by other shipment-specific characteristics. 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. For identification of the shipment-specific effects, w_{ij} is defined as a function where shipment-specific covariates are interacted with distance terms.

Here we first specify u_{ij} as the linear combination of four segments of landside and maritime shipping distances and transshipment:

$$u_{ij} = \gamma_d d_{ij} + \phi_E \times T_j \times m_{E,ij} + \phi_L m_{L,j} + \phi_A \times T_j \times m_{A,ij} + \alpha T_j \tag{3}$$

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.

We 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 (non-U.S. American/Caribbean ports). Thus, for the case of 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 we 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:

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

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.

As mentioned earlier, the shipment-specific effects w_{ij} are specified as a function of shipment-specific covariates interacted with distance terms for identification of the shipment-specific effects. We 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 is defined as follows:

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

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. We 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 $\boldsymbol{X}_i$. Here a shipper means a company at the shipping origin who is a sender of shipments to the destination, not a shipping service company. Plugging Equations 3, 4 and 5 into Equation 2, the model becomes:

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

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, we consider if the hub-and-spoke shipping economies and distance friction occur 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. With this difference in the logistic arrangement, hub-and-spoke shipping economies are allow to differ between transshipment and direct routes.

We examine if the hub-and-spoke shipping economies and distance friction happen with different magnitudes 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 6 cannot confirm if and how the effects of distance friction and hub-and-spoke configuration are different by transshipment, we expand Equation 6 by adding distance, hub-and-spoke configuration terms and shipment-specific covariates interacted with the transshipment dummy T_j as follows:

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

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.

Estimation Issues

In approaching the choice problem of freight routing, we 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, we 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, we 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. We generate choice sets that differ across individual shipments for the sake of computational efficiency in estimation. For our 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, we 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, we 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, we only consider as feasible the alternatives whose inland shipping distance is under 750km. Using the 1.5 times cutoff can exclude non-chosen alternatives with an unrealistically large landside shipping distance without biasing the results since their chance of selection is asymptotically null, while the computational burden. 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.

Empirical Results

Baseline Results

We first estimate a mixed logit model as defined in Equation 6 to examine the effects of distance and of the hub-and-spoke configuration on the routing of shipments (Table 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, we 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, we can confirm that the estimation results are robust and do not exhibit omitted variable bias.

Consistently with the existing literature, the estimation results confirm the inverse relationship between distance and trade flow. All columns in Table 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. We 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 ($e^{-0.06786/100} - 1 = -0.068\%$). The large value of the landside shipping distance coefficient indicates that the choice of a route is more sensitive to the landside shipping distance than to the maritime one.

We 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.

We also confirm that variables associated with the hub-and-spoke configuration have significant effects on shipping flows. 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 increased by 0.598 % ($e^{0.59964\times\ln 1.01} - 1 = 0.598\%$). 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 % ($e^{0.70239\times\ln 1.01} - 1 = 0.701\%$) 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 show 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. Our 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 besides the shipping distance, such as how freight is delivered in each stage of the trade logistic process from location to location, and the spatial qualities of hub ports traversed along the route.

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, we estimate a model (Equation 7) that compares these effects along ETS and WTS routes vis-à-vis the direct route. Coefficient estimates are reported in Table 3. 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 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 4) and discussed hereafter. We first find that intermediacy of the final port has 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, we find a limited degree of consistency in the signs of the effects of other hub-and-spoke configuration variables across type of routes, but instead mostly variability across route types. The latter indicates that 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 and 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 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, we 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 flows 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 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 4). In each scenario, the hub-and-spoke system has a distinct shape that best fits the requirements of a 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. It should be noted that the Jones Act imposes a severe trading restriction that the process of short-haul transshipment can take place only with U.S.-flagged ships (Rodrigue and Notteboom 2010a, 2010b). According to the Jones Act, foreign ships cannot deliver cargo between U.S. ports for short-haul shipment, so bulk shipments received from Europe via foreign ships should be broken into smaller shipments for redistribution to different U.S. destination ports before they enter the U.S. territory. In this respect, it is probable that non-U.S. West Atlantic final ports perform the hub operation instead of U.S. ports and is mainly dedicated to the redistributing to various U.S. destination ports (Brooks and Frost 2004, Rodrigue and Ashar 2016).

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.

Our 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., we 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 the 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, we found that hub-and-spoke shipping economies manifest themselves 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 relationships and their geographies. 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.

Even though our research provides fruitful research and policy implications, it is worth mentioning certain limitations that may set the course on directions for future research. First, due to the limitations of information conveyed in the PIERS data, we could not incorporate shipper variables. Different characteristics of a shipper could be influential in the shipping process and may be important in explaining route choice behaviors, especially regarding the hub-and-spoke configuration. For example, a shipper may have a business relationship with a shipping line company that sets up supply chain schedules, like whether to transship and, if so, which hub port to use, warehousing and inventory planning. These business relationships related to supply chain may be contingent upon characteristics of shippers, such as the shipper's size, main area of business and the management strategy with regard to vertical integration.

Also, since we could only investigate shipping records collected for a month, October 2006, it was impossible to consider the seasonality of shipments and possible changes in route selection by season. A possible scenario would be for a shipper to switch from a direct route to en-route transshipment to take advantage of rate changes or reconfiguration of services due to the seasonality of the demand for shipments. Conversely, a shipper may find it more efficient to switch to a direct service even if a higher rate is charged when demand escalades during the preholiday season. Using shipment records that span a longer period would allow us to examine and control the seasonality of shipping behaviors and to better elaborate how the hub-and-spoke configuration dampens distance friction of trade shipments.

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Note

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

Table 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)

Table 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	ln(Scale of Landside Operations)			0.60778***	0.59964***
Hub-and-spoke	(Landside Inbound Freight)			(0.01125)	(0.01127)
characteristics	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	Landside Distance		-0.66463***		-0.39851**
Controls	× Unit Value		(0.12050)		(0.12324)
(Interacted with	Long-haul Maritime Distance		-0.68100***		-0.44328***
distances)	× 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.

Table 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 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	(+)	(+)

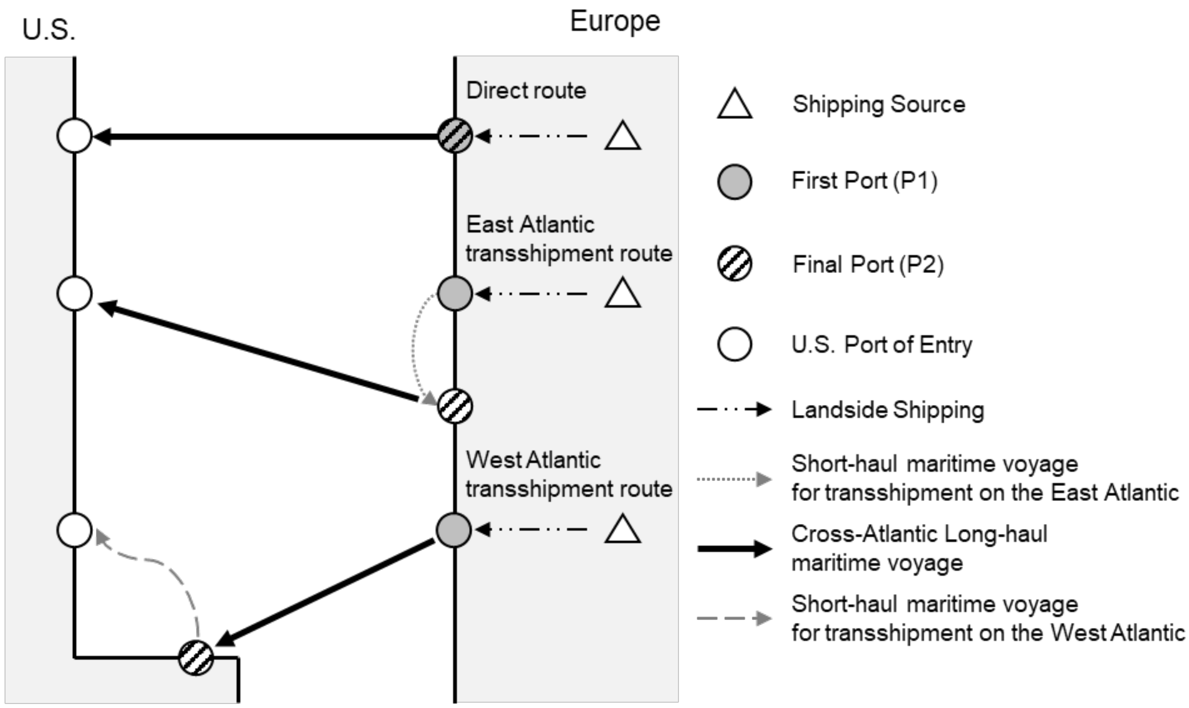
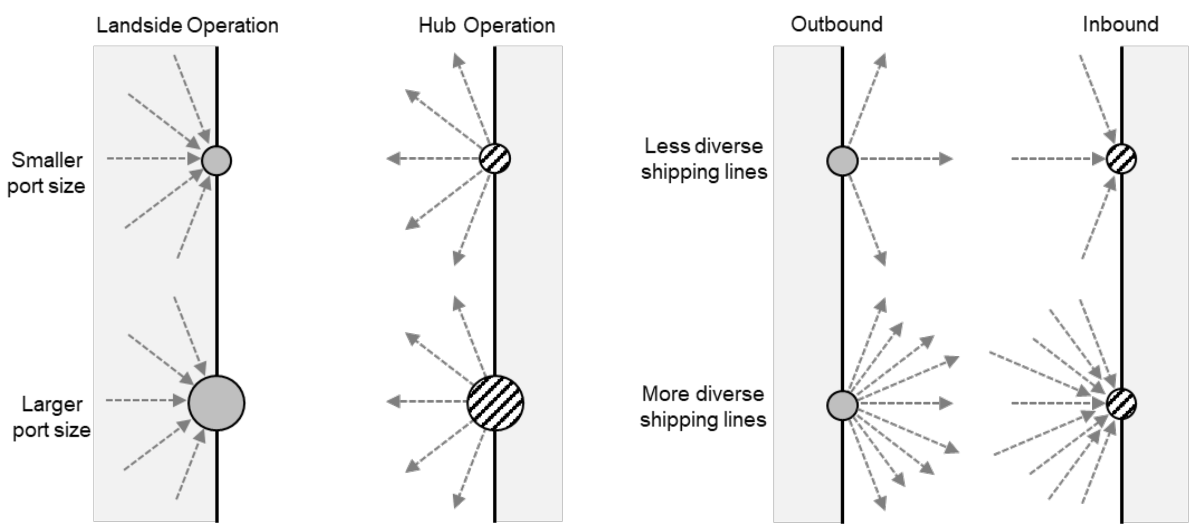


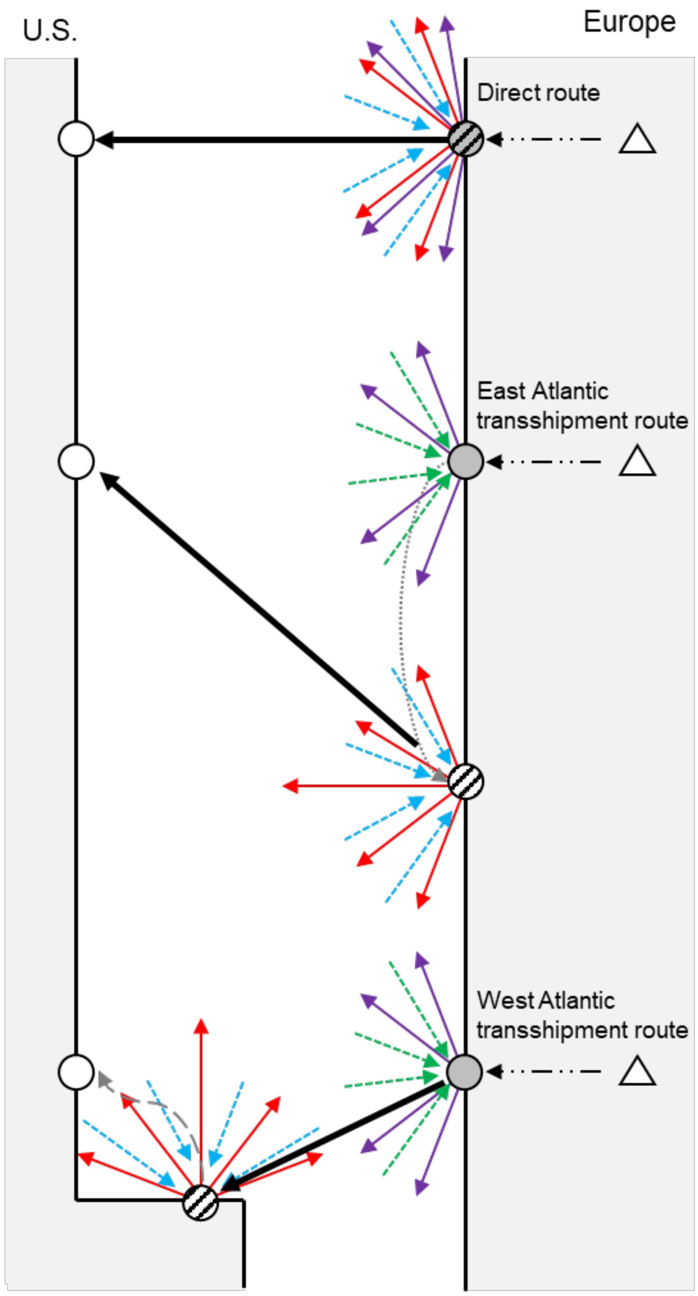
Figure 1 Direct and transshipment routes and forwarding and final ports

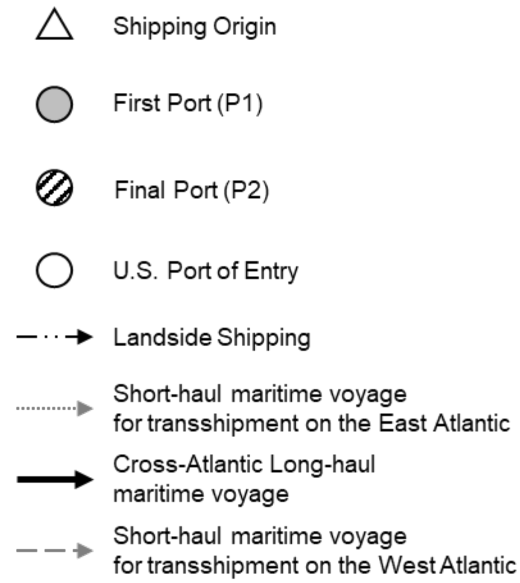


(a) Scale Economies

(b) Shipping Line Diversity

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





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

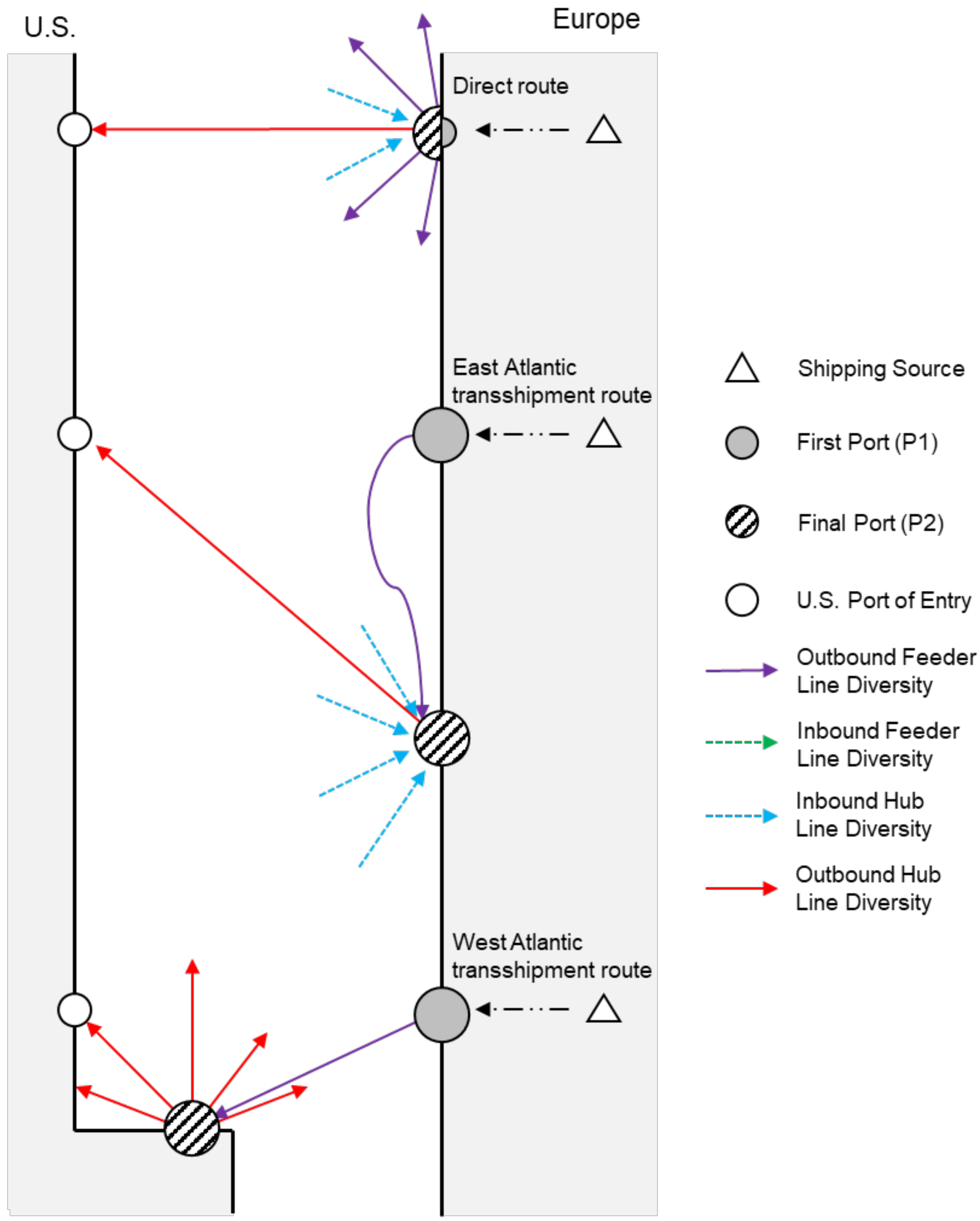


Figure 4 Schematic shapes of the hub-and-spoke system on each route

References

Behrens, K., Gaigné, C., Ottaviano, G.I.P., and Thisse, J.F., 2006. Is remoteness a locational disadvantage? *Journal of Economic Geography*, 6 (3), 347–368.

Bergstrand, J.H., 1985. The gravity equation in international trade: Some microeconomic foundations and empirical evidence. *The Review of Economics and Statistics*, 67 (3), 474–481.

Berthelon, M. and Freund, C., 2008. On the conservation of distance in international trade. *Journal of International Economics*, 75 (2), 310–320.

Blainey, G., 1966. *The tyranny of distance: how distance shaped Australia's history?* Melbourne, Australia: Sun Books.

Bleaney, M. and Neaves, A.S., 2013. Declining distance effects in international trade: some country-level evidence. *World Economy*, 36 (8), 1029–1040.

Brooks, M.R. and Frost, J.D., 2004. Short sea shipping: A Canadian perspective. *Maritime Policy and Management*, 31 (4), 393–407.

Buch, C.M., Kleinert, J., and Toubal, F., 2004. The distance puzzle: on the interpretation of the distance coefficient in gravity equations. *Economics Letters*, 83 (3), 293–298.

Cairncross, F., 1997. *The death of distance: how the communications revolution will change our lives*. Boston, MA: Harvard Business School Publications.

Carrère, C. and Schiff, M., 2005. On the geography of trade: distance is alive and well. *Revue économique*, 56 (6), 1249–1274.

Center for International Earth Science Information Network - CIESIN - Columbia University and Information Technology Outreach Services - ITOS - University of Georgia [CIESIN-ITOS], 2013. Global roads open access data set, version 1 (gROADSv1) [online]. Available from: https://doi.org/10.7927/H4VD6WCT [Accessed 9 Jun 2020].

Coe, D.T., Subramanian, A., and Tamirisa, N.T., 2007. The missing globalization puzzle: Evidence of the declining importance of distance. *IMF Staff Papers*, 54 (1), 34–58.

Coe, D.T., Subramanian, A., Tamirisa, N.T., and Bhavnani, R., 2002. *The missing globalization puzzle*. No. No. 02/171.

Deardorff, A. v., 1998. Determinants of bilateral trade: does gravity work in a neoclassical world? *In*: J.A. Frankel, ed. *Regionalization of the world economy*. Chicago, IL: University of Chicago Press, 7–32.

Disdier, A.-C. and Head, K., 2008. The puzzling persistence of the distance effect on bilateral trade. *Review of Economics and Statistics*, 90 (1), 37–48.

Eldridge, J.D. and Jones, J.P., 1991. Warped space: a geography of distance decay. *Professional Geographer*, 43 (4), 500–511.

Fleming, D.K. and Hayuth, Y., 1994. Spatial characteristics of transportation hubs: centrality and intermediacy. *Journal of Transport Geography*, 2 (1), 3–18.

Forer, P., 1978. A place for plastic space? *Progress in Human Geography*, 2 (2), 230–267.

Fratianni, M. and Marchionne, F., 2012. Trade costs and economic development. *Economic Geography*, 88 (2), 137–163.

Fujita, M. and Mori, T., 1996. The role of ports in the making of major cities: self-agglomeration and hub-effect. *Journal of Development Economics*, 49 (1), 93–120.

Fujita, M. and Mori, T., 2005. Transport development and the evolution of economic geography. *Portuguese Economic Journal*, 4 (2), 129–156.

Gallego, N., Llano, C., de La Mata, T., and DÍaz-Lanchas, J., 2015. Intranational home bias in the presence of wholesalers, hub-spoke structures and multimodal transport deliveries. *Spatial Economic Analysis*, 10 (3), 369–399.

Ganapati, S., Wong, W.F., and Ziv, O., 2021. *Entrepot : Hubs, Scale, and Trade Costs*. No. w29015.

Gatrell, A.C., 1983. *Distance and space: a geographical perpsective*. Oxford, UK: Clarendon Press.

Glaeser, E.L. and Kohlhase, J.E., 2004. Cities, regions and the decline of transport costs. *In*: R.J.G.M. Florax and D.A. Plane, eds. *Fifty Years of Regional Science*. Berlin, Heidelberg: Springer, 197–228.

Guerrero, D., Grasland, C., and Ducruet, C., 2016. Explaining international trade flows with shipping-based distances. *In*: *Maritime Networks: Spatial Structures and Time Dynamics*. 302–320.

Hall, P. v. and Jacobs, W., 2010. Shifting proximities: the maritime ports sector in an era of global supply Chains. *Regional Studies*, 44 (9), 1103–1115.

Head, K. and Mayer, T., 2013. What separates us? Sources of resistance to globalization. *Canadian Journal of Economics*, 46 (4), 1196–1231.

Hesse, M., 2013. Cities and flows: re-asserting a relationship as fundamental as it is delicate. *Journal of Transport Geography*, 29, 33–42.

Hesse, M. and Rodrigue, J.-P., 2004. The transport geography of logistics and freight distribution. *Journal of Transport Geography*, 12 (3), 171–184.

Hummels, D., 2007. Transportation costs and international trade in the second era of globalization. *Journal of Economic Perspectives*, 21 (3), 131–154.

Hummels, D. and Skiba, A., 2002. A virtuous circle? Regional tariff liberalization and scale economies in transport. *In*: A. Estevade-Ordal, D. Rodrik, A.M. Taylor, and A. Velasco, eds. *Integrating the Americas: FTAA and beyond*. Cambridge, MA: Harvard University Press.

Janelle, D.G. and Beuthe, M., 1997. Globalization and research issues in transportation. *Journal of Transport Geography*, 5 (3), 199–206.

Kashiha, M., Depken, C., and Thill, J.-C., 2016. Border effects in a free-trade zone: evidence from European wine shipments. *Journal of Economic Geography*, 16 (6), 1–23.

Knowles, R.D., 2006. Transport shaping space: differential collapse in time-space. *Journal of Transport Geography*, 14, 407–425.

Krugman, P., 1993. The hub effect: or, threeness in interregional trade. *In*: W.J. Ethier, E. Helpman, and J.P. Neary, eds. *The Policy and Dynamics in International Trade*. Cambrige: Cambrige University Press, 29–37.

Kuby, M. and Reid, N., 1992. Technological Change and the Concentration of the U.S. General Cargo Port System: 1970-88. *Economic Geography*, 68 (3), 272–289.

Lendle, A., Olarreaga, M., Schropp, S., and Vézina, P.L., 2016. There goes gravity: eBay and the death of distance. *Economic Journal*, 126 (591), 406–441.

Malchow, M. and Kanafani, A., 2001. A disaggregate analysis of factors influencing port selection. *Maritime Policy and Management*, 28 (3), 265–277.

Malchow, M.B. and Kanafani, A., 2004. A disaggregate analysis of port selection. *Transportation Research Part E: Logistics and Transportation Review*, 40 (4), 317–337.

McFadden, D., 1978a. Modeling the choice of residential location. *Transportation Research Record*, 673, 72–77.

McFadden, D., 1978b. Modelling the choice of residential location. *In*: A. Karlqvist, L. Lundqvist, F. Snickars, and J.W. Weibull, eds. *Spatial Interaction Theory and Planning Models*. Amsterdam, The Netherlands: North-Holland, 75–96.

Mori, T., 2012. Increasing returns in transportation and the formation of hubs. *Journal of Economic Geography*, 12 (4), 877–897.

Mori, T. and Nishikimi, K., 2002. Economies of transport density and industrial agglomeration. *Regional Science and Urban Economics*, 32 (2), 167–200.

Oak Ridge National Laboratory, 2000. Global shipping lane network dataset [online]. Available from: http://geocommons.com/datasets?id=25 [Accessed 12 Jun 2020].

O'Kelly, M.E., 1998. A geographer's analysis of hub-and-spoke networks. *Journal of Transport Geography*, 6 (3), 171–186.

O'Kelly, M.E. and Bryan, D.L., 1998. Hub location with flow economies of scale. *Transportation Research Part B: Methodological*, 32 (8), 605–616.

Ortúzar, J. de D. and Willumsen, L.G., 2011. *Modeling Transport*. Hoboken, NJ: John Wiley & Sons.

Plane, D.A., 1984. Migration space: Doubly constained gravity model mapping of relative interstate seperation. *Annals of the Association of American Geographers*, 74 (2), 244–256.

Redding, S.J. and Sturm, D.M., 2008. The costs of remoteness: evidence from German division and reunification. *American Economic Review*, 98 (5), 1766–1797.

Rietveld, P. and Vickerman, R., 2004. Transport in regional science: the 'death of distance' is premature. *Papers in Regional Science*, 83 (1), 229–248.

Robertson, P.E. and Robitaille, M.C., 2017. The tyranny of distance and the gravity of resources. *Economic Record*, 93 (303), 533–549.

Rodrigue, J.P. and Ashar, A., 2016. Transshipment hubs in the New Panamax Era: The role of the Caribbean. *Journal of Transport Geography*, 51, 270–279.

Rodrigue, J.P. and Notteboom, T., 2010a. Foreland-based regionalization: integrating intermediate hubs with port hinterlands. *Research in Transportation Economics*, 27 (1), 19–29.

Rodrigue, J.P. and Notteboom, T., 2010b. Comparative North American and European gateway logistics: The regionalism of freight distribution. *Journal of Transport Geography*, 18 (4), 497–507.

Steven, A.B. and Corsi, T.M., 2012. Choosing a port: An analysis of containerized imports into the US. *Transportation Research Part E: Logistics and Transportation Review*, 48 (4), 881–895.

Thill, J.C., 1992. Choice set formation for destination choice modelling. *Progress in Human Geography*, 16 (3), 361–382.

Thill, J.-C., 2011. Is spatial really that special? A tale of spaces. *In*: V. v. Popovich, C. Claramunt, T. Devogele, M. Schrenk, and K. Korolenko, eds. *Information Fusion and Geographic Information Systems*. Berlin, Germany: Springer, 3–12.

Tiller, K.C. and Thill, J.-C., 2015. Spatial patterns of landside trade impedance in containerized South American exports. *Journal of Transport Geography*, 58, 272–285.

Tobler, W.R., 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography*, 46, 234–240.

Train, K., 2009. *Discrete Choice Methods with Simulation*. New York, NY: Cambridge University Press.

Wang, C. and Wang, J., 2011. Spatial pattern of the global shipping network and its hub-and-spoke system. *Research in Transportation Economics*, 32 (1), 54–63.

Xu, H. and Itoh, H., 2017. Density economies and transport geography: evidence from the container shipping industry. *Journal of Urban Economics*, 105, 121–132.