Explaining international trade flows with shipping-based distances

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Despite the strong reliance of world trade on maritime transport[1], little has been done to investigate their actual interdependencies. The usefulness of maritime transport to "take the pulse of world trade and movement" (Ullman, 1949) has somewhat faded, while scholars interested in shipping and ports have focused increasingly on operational aspects rather than on broader socio-economic linkages (Ng and Ducruet, 2014). Many reports on world trade and the economy simply ignore maritime transport while focusing primarily on air transport, which is believed to have largely contributed to the shrinking of distances (Nelson, 2008)[2] . Air transport is also more often associated with the vitality, image, and future of regions and urban growth, whereas ports and shipping have lost their initial socio-economic importance for localities (Jacobs et al., 2010).

This chapter, however, wishes to go further into measuring the maritime dimension of trade flows. Existing analyses practically do not take into account the underlying physical (transport) architecture by which such flows are made possible (see also Hall and Hesse, 2012). In particular, studies using spatial interaction models remain very abstract, as they use crow's flight distances to explain trade flows among country pairs (McCallum, 1995, CEPII). This is somewhat unrealistic, given that information technologies and telecommunications complement and facilitate rather than replace purely physical flows of goods along the transport and logistics chain, which includes many detours and overcomes the friction of space in a very specific way (Hesse and Rodrigue, 2004). We believe that results from the application of the gravity model to world trade flows can noticeably improve if we include more practical logistics distances. In particular, maritime transport does not follow an infrastructure of track and therefore belongs to the class of non-planar spatial networks based on the design of observed flows (Ducruet and Lugo, 2013). Thus, the sole nautical distance between two countries cannot account for the true "maritime distance" even though it may include aspects of speed and size of vessels. Instead, maritime transport in this paper

[1] It is estimated that more than 90 percent of world trade volumes are carried by sea transport (International Maritime Organisation, 2014)

[2] Interestingly in this report, the analysis of "global urban accessibility" does not even include air transport linkages but rather, maritime flows alongside other elements.

is understood as the functional link between two countries based on operational aspects or observed flows. Although the observed maritime flows are in some way part of the broader trade flows, specific network configurations and logistical arrangements made by ocean carriers make them rather specific and not only a "part of the whole". The maritime network architecture is thus considered in this paper as a facilitator rather than as a sole component of international trade. Our main hypothesis is that on average, country pairs well connected by such network services will be favoured in terms of trade. Liner shipping connectivity is thus seen in this chapter as a trade facilitator against distance friction.

The remainder of this chapter is as follows. The next section offers a wider literature review on the links between trade and maritime transport to strengthen the background and originality of our approach and main hypothesis. Then we go further into the methodological aspects of a global analysis using shipping networks as distance parameters into the gravity model destined to explain trade flows among world countries. Afterwards, we present the main findings of the study, and this is followed by a discussion and conclusion on the main lessons learned.

World trade and global maritime transport

Patterns of global maritime flows

Overall, the role of maritime transport is to overcome separation by sea among trading partners. The absence of a track infrastructure allows great flexibility in designing maritime routes which are, in turn, constrained by physical (the shape of coastlines, climatic conditions, tidal ranges), political (forbidden waters for certain fleet nationalities, trade embargoes, customs regulations), and technical (quality of port services, accessibility of port terminals, overall port costs) factors. Especially in liner shipping, the architecture of container flows is also shaped to a large extent by the specific network configurations of ocean carriers. Thus, container shipping is a trade-off between shippers' needs (call frequency, accessibility, transit time, reliability) to connect markets and carriers' imperatives (ship routing, size, number of strings, geographic coverage) to deploy their services to meet demand (Notteboom, 2006). Fast increases in vessel speed, size, and frequency as well as congestion bottlenecks in traditional port cities made it necessary for shipping lines to rationalise their services by reducing the number of port calls and concentrating them at a few large transhipment hubs located such that they optimised transport and limited deviation from the trunk line followed by mother vessels (Zohil and Prijon, 1999). A global equatorial beltway or circumterrestrial route has thus emerged combining bundling services (round-the-world, pendulum) and transhipment services (hub-and-spokes, relay-interlining) within and between the connected regions (Ducruet and Notteboom, 2012a).

A number of empirical analyses of global maritime flows were proposed in recent years, mostly to describe the topological structure of the network, without direct connection to trade flows. Some scholars have applied several measures from complex networks research to verify the scale-free and small-world dimensions of the global maritime network, mostly for container shipping flows (Deng et al., 2009; Hu and Zhu, 2009) as well as other fleet types (Kaluza et al., 2010; Ducruet, 2013). This work confirmed that as a scale-free network, the global shipping network is composed of a few large nodes having many connections to other nodes, and a majority of small nodes with only a few links. This was also confirmed by applying more classic methods such as single linkage analysis revealing dominant hub ports and their affiliated nodal regions (Wang and Wang, 2011) and statistical measures showing the growing concentration of container traffic among world ports since the early 1970s (Ducruet and Notteboom, 2012b). Other work has searched for interdependencies with airline networks (Parshani et al., 2010). While all these studies have defined the network based on ports as nodes and vessel movements (or schedules) as links between them, other scholars have also focused on large regions as nodes (Joly, 1999; Li et al., 2014).

Such works could have shed new empirical light on both carrier and trade factors in shaping global maritime flows. On the one hand, carrier factors fostered the emergence of intermediate hubs ensuring intra- and interregional shipping connectivity (see also Frémont, 2007; Rodrigue and Notteboom, 2010). Among those hubs, some were also hinterland gateways enjoying land-based centrality, such as Rotterdam and Hamburg, while others were mostly defined by their intermediacy, such as Singapore and Gioia Tauro (Ng, 2006). On the other hand, the geographic coverage of maritime flows also revealed their high concentration on shorter (kilometric) distances, preferential linkages among neighbouring ports, and noticeable regional shifts such as most of African traffic being increasingly polarised by Asia, and a decreasing role of Europe in global maritime flows (see also Ducruet et al., 2014). Despite its initial specification in relation with global trade flows, the model proposed by Tavasszy et al. (2011) on multimodal networks and flows was mostly designed to address the likely impacts of different scenarios on the level and distribution of port container throughputs. For instance, they calculated that a new polar cap shortcut or a better developed Europe-Asia railway land-bridge would not provoke enormous shifts of container flows from routes going through Suez. While their results proved to be accurate and realistic, they did not further link their model with trade flows.

Trade and shipping interdependencies

The interdependencies at stake between trade and shipping have been researched by a number of scholars in recent years, from various perspectives. For instance, it has been demonstrated that coastal economies are favoured compared with landlocked countries due to the role of transportation gateways (Behrens et al., 2006), to such an extent that landlocked countries assume 50 percent more transport costs than coastal countries (Limao and Venables, 2001). The influence of port infrastructure quality and efficiency on shipping costs was also underlined by Clark et al. (2004) and Haddad et al. (2006). Perhaps the most relevant approach to the current paper is the one by Bernhofen et al. (2013) on the effects of the container revolution on world trade. Using time series data for 1962-1990, the authors particularly underlined the stronger effect of container adoption (port and railway) on trade growth compared with the effects of trade liberalization, mostly for North-North trade. While such results confirm the importance of (container) shipping for world trade, the role of developing countries and notably the export-led newly industrialized countries of Asia remained little discussed.

The reason why analyses of shipping and of trade remain apart is mostly practical. Trade statistics by transport mode do not exist, while shipping statistics refer to tonnage rather than to the value of the goods carried by ships and handled at port terminals. Such differences in data units are aggravated by differences in the respective definitions of flows. Unlike trade statistics, shipping and port statistics often include transhipment, i.e. transit trade between origin and destination, thus complicating their direct comparison. Another aspect is that tonnage data rarely mentions the origins and destinations of flows. On a world level, the International Road Transport Union (IRU) ceased to publish country-level tonnage figures after 1996, which could then be complemented by the yearbooks of the United Nations[3] . But the most striking change in data availability is the disappearance of the Maritime Transport Study published by the United Nations as *Commodity Trade (by Sea) Statistics*[4] until the 1980s. It was, to our knowledge, used in only one research paper in the whole academic literature (van den Bremen and de Jong, 1986) for describing world patterns of maritime trade flows. Yet, the authors used the information to measure and map the amount of flows per region and per commodity rather than focusing on flows between regions of the world. Finally, indicators available on a country basis, such as the Liner Shipping Connectivity Index (LSCI), can be considered as a “proxy of the accessibility to global trade” and “jointly considered as a measure of connectivity to maritime shipping and as a measure of trade facilitation” (Rodrigue, 2014). However, such indicators are not related with trade itself and remain bound to transport and logistics performance measurements.

Data and methodology

In this work a spatial interaction model is used as a tool to measure the influence of the frequency of containerized shipping services on trade. Instead of focusing on shipping as flows, as in the aforementioned literature on global maritime networks, it considers shipping services as a functional distance among countries of the world.

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[3] Related publications are: *World Transport Data* (IRU, 1996), *Statistical Yearbook* (United Nations, 2000), and *Review of Maritime Transport* (UNCTAD, 2001).

[4] Coastal countries included in this study are specified in Appendix 17.1

Data on international trade

Unfortunately for researchers in maritime transportation, an exhaustive large-scale world database of freight flows in tonnes is not available. Empirical evidence on international freight flows in tonnes can be gathered only from national databases (such as customs), which are not comprehensive on a worldwide basis. For these reasons, we have decided to make use of *Chelem*, a single database of international trade in constant dollars, created by the French research centre in international economics (CEPII). We know that it is an imperfect proxy of freight flows since these are sensitive to fluctuations in market prices as well as changes in interest and exchange rates. The impact of these fluctuations is partially offset by providing segmented results of the model by types of cargo[5]. Data on distances between country capitals used in the spatial interaction model has also been obtained from *Chelem*.

This work is focused on containerized shipping, which operates on a fixed geographic itinerary and publicly advertised sailing schedule. In general, containerized transport mainly consists of manufactured goods, usually of high value. Since in our trade database there is no specification on the type of packaging, we have created a *containerisable* category with the cargo categories that seem most likely to be carried in containers. Obviously, there is no firm rule one way or the other on this issue, and one type of cargo can be either containerized or not depending on many different parameters such as the size of the shipment or the handling tools available at seaports. For example, cereals that can be either transported in containers or in bulk ships are considered non-containerisable since most volumes are conveyed in bulk carriers. Steel coils, which are sometimes differently packed and conveyed in specific ships, are however considered as containerisable. Another shortcoming of international trade databases is their lack of specification of the mode of transport. Even if most trade in value is conveyed by ships (70 percent according to UNCTAD, 2013), a substantial part of it is also conveyed by ground transport and plane. In this study, the impact of non-maritime modes seems to have been reduced by the structure of the sample, which consists exclusively of countries with access to maritime networks (Figure 17.1).

[Figure 17.1 here]

Data on shipping services

Shipping services have been calculated using the *Lloyd's List* database about the movements of ships in 1996 and 2006. The latter are based on the number of weekly opportunities to send cargo between two ports on the same ship. The opportunities have been aggregated at the level of countries to match with the data on trade flows. Unfortunately, the data does not take into account the indirect opportunities to link

[5] The content of the ten cargo families considered in this work is specified in Appendix 17.2.

two ports. Therefore the accessibility of regions usually served by feeder services via transhipment hubs (Africa, Oceania, and South America) is underestimated. However, it could be argued that in most industries there is a preference for direct maritime connections, generally considered more reliable and faster than indirect ones (Woxenius, 2012). The impact of transit time in trade is potentially high. But it could vary from one service to another, even if we consider the same couple of ports (see Table 17.1). This variability is linked both to the itinerary (through canals or not) and the number of scales of the service. The use of average transit time (roughly correlated with distance) has not been tested, since it is difficult to estimate and does not seem to provide relevant information to the model.

[Table 17.1 here]

Finally, the two measures used to explain the geographical distribution of international trade (distance and frequency of containerized services) reflect different but complementary dimensions of contemporary systems of production. These dimensions have been analysed by empirical work about the extension of automotive production networks (Woxenius, 2006) that considers five different temporal elements (Figure 17.2). Between them only transport time (a) and order time (b) are linked with speed, and by extension with geographical distance. The other time elements (timing, punctuality and frequency) seem to be much more related to the regularity and reliability of transport services, and then more or less directly linked with the frequency of transport services. So, traditional spatial interaction models explain trade only by taking into account the two first temporal elements (order time and transport time) but completely neglect the three last ones. By using the frequency of containerized shipping services, this chapter aims to shed some light on the other temporal elements that remain largely unknown.

[Figure 17.2 here]

Methodology

Spatial interaction models are employed to evaluate the impact of distance and the frequency of shipping services on trace for different types of cargo. They provide an explanation of the spatial pattern of trade flows between countries in terms of value. After testing different kinds of models (see Appendix 17.3), the spatial interaction models selected are those that provide the highest explanatory power. They are formulated as follows:

(a) $\mathrm{Fij} = A\mathrm{i}\cdot\mathrm{Oi}\cdot\mathrm{Bj}\cdot\mathrm{Dj}\cdot\mathrm{dij}_1{}^{\alpha}$

(b) $\mathrm{Fij} = A\mathrm{i}\cdot\mathrm{Oi}\cdot\mathrm{Bj}\cdot\mathrm{Dj}\cdot\mathrm{dij}_1{}^{\alpha}\cdot\mathrm{dij}_2{}^{\gamma}$

where O_i is the total value of exports of the country called i; D_j is the total value of imports of the country called j (see table 1); d_{ij} is the separation (Euclidean distance/frequency of shipping services) between i and j; α is the decay parameter associated with distance (d_{ij1}); γ is the elasticity associated with the frequency of shipping services (d_{ij2}); and A_i· and B_j· are the balancing factors ensuring that the origin i and destination j constraints are satisfied. When a country is exporting, it is referred to as “i” and when a country is importing, it is referred to as “j”.

The choice of measure of distance influences the results of the spatial interaction model. The Euclidean distance between capitals has been selected because it seems to be more consistent with the situation of most of the countries analysed, where more than one port handles international trade. Moreover, the explanatory power of the model is slightly higher when the distance between capitals is used, as compared to the distance between centroids.

[Table 17.2 here]

The data used is a matrix of freight flows between countries (Table 17.2). The value of r^2_1 is the part of the total variance explained by the model. It is a measure of the goodness of fit of the model to explain the spatial distribution of flows between the countries. A r^2_1 of 100 percent would indicate that the regression line perfectly fits the data. This means that the spatial distribution of flows between countries can be perfectly predicted by the total exports of the country i, the total imports of country j, and the distance separating both. A second parameter r^2_2 is calculated as a measure of variance specifically explained by the distance. A third parameter r^2_3 measures the specific explanatory power of shipping services. A Poisson regression has been used to fit the spatial doubly constrained model (Fotheringham and O’Kelly, 1989; D’Aubigny et al., 2000).

Results

[Table 17.3 here]

Long-term evolution of trade (1975-2010): the impact of economic regionalization

Table 17.3 shows the results of the spatial interaction model of trade flows between coastal countries in 2006, distinguishing containerisable cargo. The model, exclusively based on traffic and distance (see equation [a], section 3.3) explains 89 percent of the geographical distribution of all flows but only half of those of containerisable cargo. Alone, the distance between countries plays an important role in the model, explaining two-thirds (69 percent) of the geographical distribution of all trade but only 21 percent of the containerised flows. Obviously distance plays a negative role in trade either or not containerisable. The average value of distance-decay parameter (α) varies between .84 and .86 (flows in dollars, including petroleum products), which means that a 10 percent increase in distance lowers trade by about 8.5 percent. Although trade between coastal countries is strongly distance-constrained, it is less than if we include inland countries, for which the average distance-decay parameter is slightly higher (Disdier and Head, 2008). This difference could be due to the lack of direct access to the sea of inland countries that would imply difficulties to reach distant markets.

[Figure 17.3 here]

Analysis of long series of data provides insight into the evolving influence of distance between coastal countries. Over the last three decades the distance decay has gone up (+.03 for all cargo, +.01 for containerized) although with periods of ups and downs. Considering that the differences in the trends of containerized and all cargo before 1985 are probably due to the rise of the price of oil after the (oil) crises in 1973 and 1979, periods of decline (1975-1990) and ascent (1990-2007) can be identified. The decline of the influence of distance in 1975-1990 seems to be linked both to the fulfillment of the main waves of containerisation (Guerrero and Rodrigue, 2014) and the removal of protectionist measures, especially in the emerging economies (Krugman, 1995). The recovery and rise of the effect of distance since 1990 should be interpreted in a broader trend since the 1950s (Head and Mayer, 2010). According to Disdier and Head (2008) three explanations can be provided to explain the long-term rise of distance-decay since the aftermath of the Second World War. The first is that technological advances such as email and the Internet may have been smaller or less ubiquitous than certain works would suggest (see for example Cairncross, 2001). Second, as suggested above, the influence of time on trade seems to be increasing (Hummels, 2001; Woxenius, 2006). Third, changes in the composition of trade might be biased towards goods with high distance costs (Bertherlon and Freund, 2004). Another explanation of this shift would be that falling transport costs (mainly derived from containerisation) push firms to trade more sophisticated goods with higher transaction costs and this would contribute to maintain distance-decay high (Duranton and Storper, 2006).

Medium-term evolution of trade (1996-2006): looking at the impact of maritime services on trade

To test the influence of the frequency of maritime transport on trade, the number of weekly shipping services has been introduced in the model. Traffic, distance, and shipping services account together for 91 percent ($r^2{}_{3)}$ of the geographic distribution of trade flows. If we eliminate mass and distance factors, the contribution of shipping services to the model is statistically significant but is globally low ($r^2{}_3$=1.4 percent). Obviously, the effect of the frequency of containerized services is a positive one (γ =.10 in 2006), which means that an increase of 10 percent in the number of weekly shipping services implies a rise in trade of about 1 percent. Therefore, greater opportunities to ship cargo from one country to another might lead to increasing opportunities for profitable trade. However, it seems that the effect of the frequency of shipping services in trade has decreased between 1996 (γ =.14) and 2006 (γ =.10). This would result from the generalization of containerized services that are today more ubiquitous than in the past, implying less spatial differentiation between trade routes. Moreover, the further development of hubbing and transhipment in containerized networks since the 1990s would have increased the relative importance of indirect connections compared to direct ones, which are those we have used.

[Table 17.3 here]

The significance of shipping services in explaining trade between coastal countries varies considerably between industries (Table 17.4). These differences mean that the needs of frequent containerized services are not equal for all industries, depending on factors such stock levels and inventory management strategies. When isolated from distance and traffic, the explanatory power of shipping services for paper and pulp (r^2_3=2.0 percent), building materials (r^2_3=1.9 percent), and machines, equipment, and arms (r^2_3=1.8 percent), is as much as four times higher than those of food and beverages ((r^2_3=.4 percent), vehicle components and engines (r^2_3=.5 percent), and precision instruments (r^2_3=.6 percent). These results are surprising. On the one hand sectors like textiles, electronics, and precision instruments, known as highly dependent on time-to-market, are not well explained by shipping services. On the other, flows generated by more traditional sectors like paper manufacturing or construction are much better explained by the frequency of transport services. One partial explanation would be the importance of other means of transport conveying the international trade generated by these sectors: air transport for long distances and ground transport for short ones. A comparison of these results with those of 1996 provides some further explanation. The explanatory power of shipping services was considerably higher for electronics (r^2_3=2.1 percent) and for precision instruments (r^2_3=2.5 percent). The shrinkage of the explanatory power of shipping services for these sectors means that they rely less on the frequency of transport services than in the past. Another possible explanation is that strategies of cost reduction in transport, implying less frequent shipments, have grown in importance within these sectors.

[Table 17.4 here]

All industries are not equally sensitive to the frequency of containerized services (Table 17.3). The most sensitive ones are also those for which its explanatory power is the highest: paper and pulp and building materials with elasticity values (γ) of .15. The high influence of the frequency of shipping services in these sectors can be due to the relatively important volumes that they generate, leading to high storage costs. The less sensitive ones are food and beverages, precision instruments, and vehicle components and engines ($\gamma = .6 - .7$). These differences mean that variations in the frequency of shipping services have unequal effects on the flows generated by different activities. It should be noted that the differences of activities with regard to shipping services sensitivity remain roughly unchanged between 1996 and 2006. The impact of shipping services has considerably decreased between 1996 and 2006 for most industries (in 2006 γ= .17). The decrease has been particularly dramatic for trade flows generated by wood and furniture, plastic objects, and metallic structures and hardware.

[Table 17.5 here]

According to the model, the distance and frequency of shipping services thus explain to a large extent the spatial variation of international trade flows. However, this type of analysis naturally raises the question of deviations from the predictions. Table 17.5 shows the differences between the observed and expected (as of the model) distributions of flows. The left column shows trade routes with larger flows than expected (underestimations), the right column outlines those with smaller flows than expected (overestimations). In order to make the results more easily understandable, deviations between countries have been aggregated at the level of regions.

A substantial number of underestimations take place between neighbouring countries within the same region. Therefore, European (31 percent), Asian (9 percent) and North American (7 percent) internal trade accounts for almost one-half the underestimations of the model. In the case of Europe and North America, this can be explained by the intense ground transportation flows between neighbouring countries within the same economic region (for example between the United States and Mexico in NAFTA or between France and Italy inside the EU). In the case of Asia, the reasons are more complex: specific political relationships between Taiwan and China, and strong economic partnerships between Japan, Taiwan, and Thailand. Other important underestimations of the model are the flows between Asian countries and the rest of the world, especially with North American countries (17 percent) and European ones (10 percent). This trade, which takes place over very long distances and with very large ships (in order to achieve economies of scale), is logically underestimated since the model only takes into account the frequency of shipping services. Moreover, a substantial share of the trade between North America and Asian countries is transhipped by foreign ports such as Singapore for Malaysia and Busan (South Korea) and Kaohsiung (Taiwan) for Japan.

Surprisingly, a substantial share of overestimations of the model can be found again in the trade within the same regions. Intra-European and intra-Asian trades account together for 40 percent of the overestimations of the model. The reason for this is quite simple, since most of these overestimations take place in trade with countries with large shipping hubs that concentrate maritime connections without being the point of origin or destination of goods. As explained above, the international trade of Asian countries such as Malaysia and Japan is largely transhipped in foreign countries such Singapore, South Korea, and Taiwan. In Europe, the trade between Germany and most Scandinavian countries is overestimated since the port of Hamburg is their main transhipment hub. Russian ports also rely on Western-European hubs such as Hamburg and Rotterdam to convey their international trade. Other important overestimations of the model are found in long-distance routes: North Atlantic and Asia-Europe, respectively, account for 25 percent and 11 percent of the total. Most of these overestimations are found in countries with large shipping hubs such as Italy (Gioia Tauro), Spain (Algeciras), Netherlands (Rotterdam), and Germany (Hamburg).

Finally, most of the deviations to the model are explained by the strategies pursued by shipping companies in terms of hub location and allocation of ships of different sizes. The hub-and-spokes networks tend to concentrate supply in a small number of seaports. The choice of a seaport as a hub by a particular shipping company is essentially determined by its more or less favourable location in relation to the demand of its hinterland and to its position in the global maritime network. It is important to avoid making excessive detours. This means that seaports that do not necessarily have a deep hinterland (such as Algeciras or Gioia Tauro) but that are located near the main shipping routes will be favoured in terms of opportunities to trade and will be overestimated by the model. On the other hand, the long distance trade of countries that rely on foreign hubs to convey their trade, such as Japan or Malaysia, will be underestimated by the model. Since shippers usually prefer to use direct connections, this deficit could eventually have a negative impact on the trade of these countries.

Discussion and conclusion

The results provided by the spatial interaction model suggest several things. First, both distance and shipping services are important variables in explaining the geographical pattern of trade flows between coastal countries. The influence of shipping services on trade is important but less than that of distance. This means that containerised cargo remain strongly distance-constrained, despite the diminution of transport costs and the increase in frequency. Contrary to what one might expect, the influence of shipping services on trade has slightly decreased between 1996 and 2006. This trend affects all types of flows, no matter the industry. The achievement of containerisation and increased hubbing by shipping lines has helped to encourage this phenomenon. The shipping-services-based model as proposed does not explain an important proportion of the variance in the dataset. There are probably some variables, other than volume and distance, which have some effect on spatial structure of flows between countries. However the simultaneous inclusion of distance and shipping services in a single model might help increase its explanatory power.

Our conclusions are valid only for a sample of coastal areas where African countries are largely underrepresented. More empirical research is necessary to make further generalisation. African countries are particularly reliant on their maritime trade, even if the type of goods exported seems to be less sensitive to sophisticated time elements like frequency. Moreover, the hinterlands of large seaports like Antwerp or Rotterdam go far beyond the national borders of Belgium and the Netherlands. Other ports, like Singapore or Marsaxlokk mainly act as transhipment hubs for the trade of other countries. So the frequency of shipping services to and from these countries can hardly explain their much weaker trade volumes. One important implication of this work is that the model has also quantified the elasticity values of shipping services for different types of cargo. This is an important finding, as it provides empirical support for visualising scenarios with regard to the impact of reducing or increasing shipping frequencies. This result could be useful for maritime companies in planning the distribution of their capacities and also for public policy to supporting certain maritime links in order to develop external trade and reduce land transport bottlenecks.

The last year of observation in this study is 2006. The increase of containerized capacities since then has considerably impacted the number of services offered in the main shipping lines, using fewer and larger ships. Moreover, reconfigurations in liner services since the financial crisis of 2008 have resulted in cargo consolidation in larger ports, leading to a global reduction of the number of direct calls and further development of feeder services to secondary ports. This will probably result in a reduction of the explanatory power of the model. It is, however, not entirely clear at this point to what extent these trends will affect how shipping services are interrelated with international trade.

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Day of the week (dep)	Departure time	Shipping Company	Transit time (days)	Day of the week (arriv)
MON	10h10	Hanjin	34	SUN
MON	14h30	UASC/ CMA CGM	41	SUN
TUE	12h55	APL/OOCL	27	MON
TUE	13h00	UASC / CMA CGM	42	TUE
WED	10h25	Hapag Lloyd	27	TUE
WED	14h30	UASC	48	TUE
THU	19h00	Cosco/Hanjin	39	MON
FRI	08h25	Maersk	37	SUN
FRI	20h20	NYK Line	27	THU
SAT	20h40	CSCL	36	SUN
SUN	12h50	OOCL / NYK	30	TUE
SUN	17h15	Maersk	35	SUN

Table 17.1 Weekly direct services between Le Havre and Hong Kong (January 2014)

To From	Country 1	Country 2	Country ...	Country j	Exports
Country 1	0	I12	I1...	I1j	Exp Country 1
Country 2	I21	0	0	I2j	Exp Country 2
Country ...	I...1	I...2	0	I...j	Exp Country ...
Country i	Ii1	Ii2	Ii...	0	Exp Country j
Imports	Imp Country 1	Imp Country 2	...	Imp Country j	

Table 17.2 Matrix of origin-destination of flows between coastal countries

2006, crow's flight distance	α	r^2_1	r^2_2
All cargo	-.86	89%	69%
Containerizable	-.84	89%	68%

Table 17.3: Results of a spatial interaction model using crow's flight distance

	1996					2006				
	α	γ	r^2_1	r^2_2	r^2_3	α	γ	r^2_1	r^2_2	r^2_3
Electronics	-.48	.14	89%	52%	2.1%	-.62	.09	87%	52%	1.1%
Textile	-.86	.12	84%	56%	1.3%	-.94	.08	86%	55%	.8%
Food & Beverages	-.96	.10	84%	61%	.8%	-.99	.06	83%	61%	.4%
Vehicle components & Engines	-.92	.12	87%	68%	.9%	-.97	.07	89%	69%	.5%
Paper & pulp	-1.01	.16	88%	75%	1.7%	-1.00	.15	87%	72%	2.0%
Building materials	-1.04	.14	88%	73%	1.1%	-1.00	.15	87%	71%	1.9%
Plastic & miscellaneous articles	-.83	.17	88%	70%	1.9%	-.91	.12	89%	71%	1.4%
Chemicals & pharmaceuticals	-.72	.12	88%	63%	1.7%	-.73	.08	86%	54%	1.2%
Metallic structures and hardware	-.88	.17	89%	72%	1.9%	-.90	.10	89%	69%	1.3%
Machines, equipment & arms	-.66	.14	89%	69%	2.5%	-.70	.09	89%	67%	1.8%
Precision instruments	-.55	.15	91%	60%	2.5%	-.61	.06	89%	53%	.6%
Wood and furniture	-1.01	.20	90%	73%	2.1%	-1.08	.12	90%	70%	1.5%
Containerizable cargo	-.73	.14	90%	71%	1.8%	-.78	.10	91%	73%	1.4%

Table 17.4: Results of a spatial interaction model using shipping services as distance measurement

Main underestimations, by region	
Intra-Europe	31%
North-Pacific	17%
Asia-Europe	10%
Intra-Asia	9%
Intra-North America	7%
Intra-South America	2%
Others	24%

Main overestimations, by region	
North Atlantic	25%
Intra-Europe	21%
Intra-Asia	18%
Asia-Europe	11%
South America-North America	4%
Russia-> Europe	2%
Others	20%

Main underestimations, by country			
CHN->USA	8%	CHN->CAN	1%
MEX->USA	4%	CHN->NLD	1%
USA->MEX	3%	ESP->FRA	1%
TWN->CHN	2%	DEU->ITA	1%
JPN->TWN	2%	ESP->PRT	1%
USA->JPN	2%	DEU->ESP	1%
MYS->USA	2%	DEU->FRA	1%
ITA->FRA	1%	FRA->ITA	1%
BEL->DEU	1%	NLD->DEU	1%
DEU->BEL	1%	BEL->ITA	1%
GBR->IRL	1%	CHN->GBR	1%
USA->KOR	1%	NLD->ITA	1%
FRA->ESP	1%	CHN->DEU	1%
JPN->THA	1%	FRA->DEU	1%
CAN->USA	1%	*Others*	*56%*

Main overestimations, by country			
DEU->USA	4%	MYS->SGP	1%
CHN->KOR	3%	DNK->DEU	1%
CHN->TWN	3%	GBR->FRA	1%
ITA->USA	2%	GBR->BEL	1%
KOR->JPN	2%	FRA->NLD	1%
FRA->GBR	2%	BRA->USA	1%
USA->ESP	2%	DEU->DNK	1%
FRA->USA	2%	BEL->GBR	1%
ESP->USA	2%	USA->FRA	1%
CHN->JPN	2%	GBR->NLD	1%
USA->ITA	1%	NLD->FRA	1%
USA->DEU	1%	CHN->THA	1%
NLD->USA	1%	DEU->NOR	1%
SWE->DEU	1%	TWN->JPN	1%
BEL->USA	1%	*Others*	*60%*

Table 17.5: Deviations of a spatial interaction model using shipping services as distance measurement

Albania, Algeria, Argentina, Australia, Bangladesh, Belgium, Brazil, Brunei Darussalam, Bulgaria, Cameroon, Canada, Sri Lanka, Chile, China, Taiwan, Province of China, Colombia, Croatia, Denmark, Ecuador, Estonia, Finland, France, Gabon, Germany, Greece, Iceland, India, Indonesia, Ireland, Israel, Italy, Ivory Coast, Japan, Kenya, Korea, Republic of, Latvia, Libya, Lithuania, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Russian Federation, Saudi Arabia, Singapore, Viet Nam, Slovenia, South Africa, Spain, Sweden, Thailand, Tunisia, Turkey, Ukraine, Egypt, United Kingdom, United States, Uruguay, Bolivarian Republic of Venezuela.

Appendix 17.1: List of countries included in this study

Containerisable: All types of cargo except		Electronics	
FT	Cars and cycles	FL	Electronic components
FU	Commercial Vehicles	FM	Consumer electronics
FV	Ships	FN	Telecommunications
FW	Aeronautics	FO	Computer equipment
HA	Iron ores	Textile	
HB	Non ferrous ores	DA	Yarns, fabrics
HC	Unprocessed minerals	DB	Clothing
IA	Coals	DC	Knitwear
IB	Crude oil	DD	Carpets
IC	Natural gas	DE	Leather
IG	Coke	Food and beverages	
IH	Refined petroleum	KA	Cereal products
II	Electricity	KB	Fats
JA	Cereals	KC	Meat
JB	Other edible agricultural	KD	Preserved meat/fish
JC	Non-edible agricultural	KE	Preserved fruits
NA	Jewellery, works of art	KF	Sugar
NB	Non-monetary gold	KH	Beverages
Vehicle components & engines		Plastic & miscellaneous manuf. articles	
FS	Vehicles components	EE	Toys & Miscellaneous mnf.
FC	Engines, turbines and pumps	GG	Plastics
Paper & pulp		GH	Plastic articles
EC	Paper and pulp	GI	Rubber articles
ED	Printing	Chemicals & pharmaceuticals	
Building materials		GA	Basic inorganic chemicals
BA	Cement	GB	Fertilizers
BB	Ceramics	GC	Basic organic chemicals
BC	Glass	GF	Pharmaceuticals
Metallic structures and miscellaneous hardware		Machines, equipment & arms	
FA	Large metallic structures	FD	Agricultural equipment
FB	Miscellaneous hardware	FE	Machine tools
Precision instruments		FF	Construction equipment
FI	Precision instruments	FG	Specialized machines
FJ	Watch and clockmaking	FH	Arms and weaponery
FK	Optics	Wood and furniture	
		EA	Wood articles
		EB	Furniture

Appendix 17.2: Families of cargo included in this study based on Chelem categories

Containerisable cargo	1996					2006				
	α	γ	r^2_1	r^2_2	r^2_3	α	γ	r^2_1	r^2_2	r^2_3
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot dij_1{}^{\alpha} \cdot dij_2{}^{\gamma}$	-.73	.14	90%	71%	1.8%	-.78	.10	91%	73%	1.4%
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot dij_1{}^{\alpha} \cdot \gamma \cdot dij_2$	.46	.00	82%	49%	1.0%	-.94	.00	91%	72%	.3%
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot \alpha \cdot dij_1 \cdot \gamma \cdot dij_2$	.00	.00	83%	51%	.9%	.00	.00	85%	56%	.0%
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot \alpha \cdot dij_1 \cdot dij_2{}^{\gamma}$	.00	.28	86%	58%	7.9%	.00	.20	88%	62%	6.3%
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot dij_1{}^{\alpha}$	-.88	N/A	89%	69%	N/A	-.90	N/A	91%	71%	N/A
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot dij_2{}^{\gamma}$	N/A	.51	82%	48%	N/A	N/A	.43	83%	47%	N/A
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot \alpha \cdot dij_1$	.00	N/A	83%	50%	N/A	.00	N/A	85%	56%	N/A
$Fij = Ai \cdot Oi \cdot Bj \cdot Dj \cdot \gamma \cdot dij_2$	N/A	.00	72%	20%	N/A	N/A	.00	72%	15%	N/A

Appendix 17.3: Results of various spatial interaction models

Figure 17.1: Countries included in this study

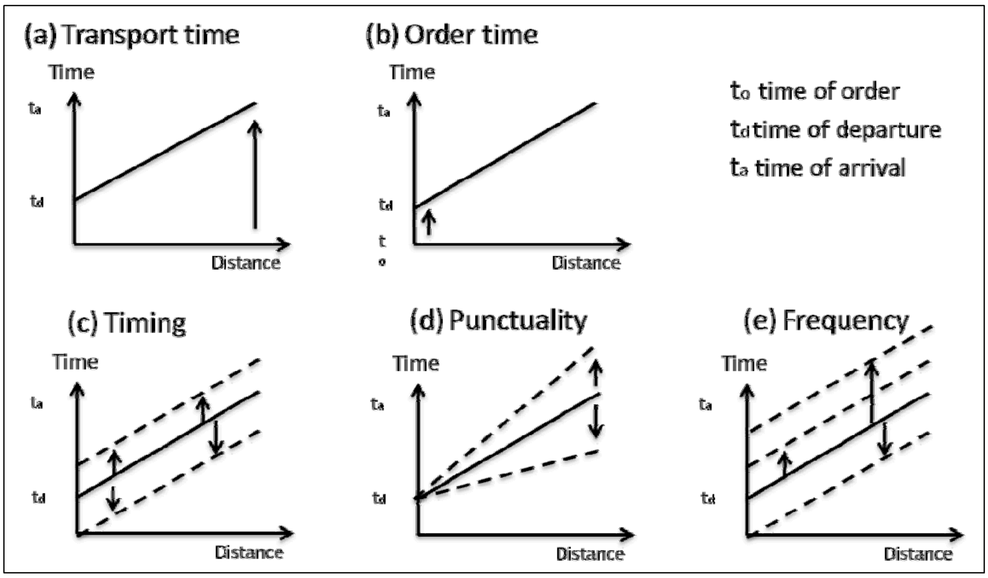

Figure 17.2: Temporal elements in production networks (Woxenius, 2006)

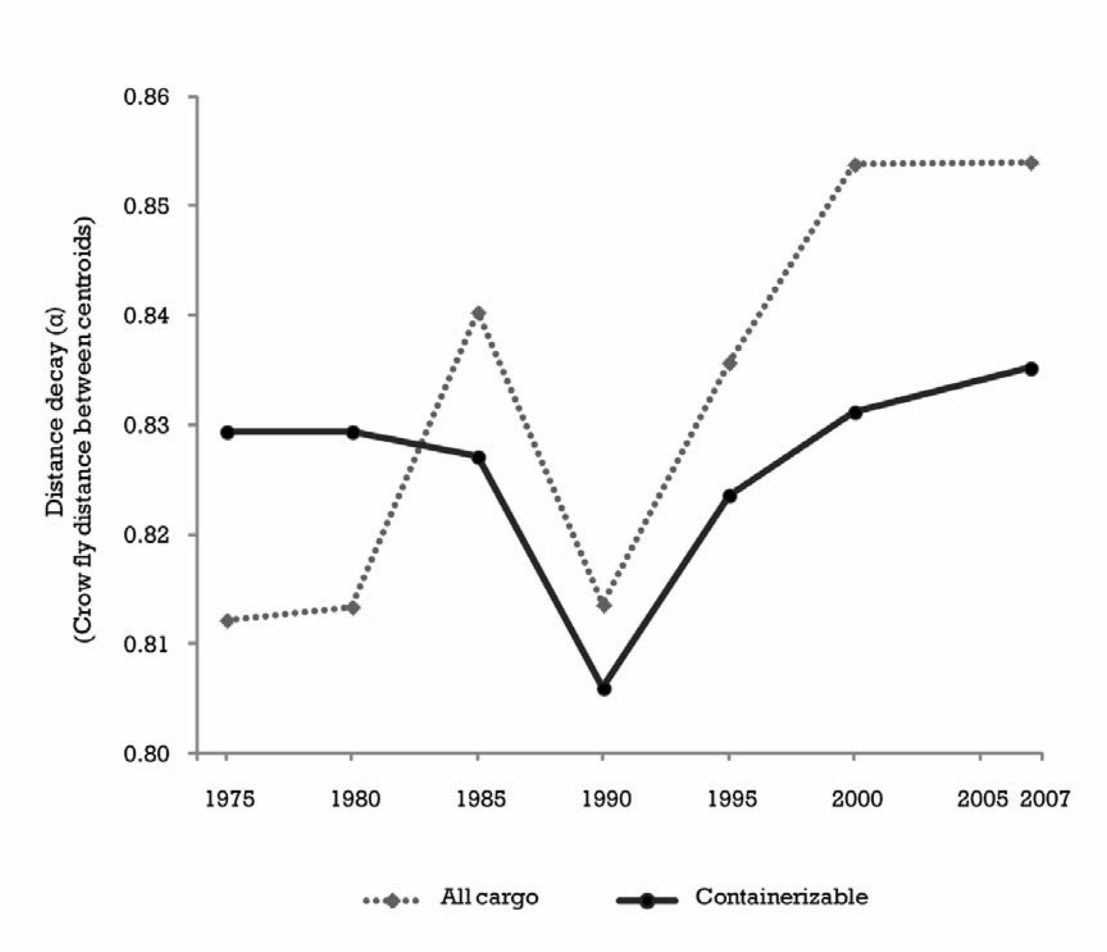

Figure 17.3: Evolution of distance decay in bilateral trade between coastal countries (1975-2007)