UNIVERSITY OF SOUTHAMPTON

FACULTY OF PHYSICAL AND APPLIED SCIENCES

Social Sciences

Three Essays in International Economics

by

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Thesis for the degree of Doctor of Philosophy

March 2014

This Doctoral Thesis is dedicated to the memory of my beloved Father Mr. Chrysostomos “Totos” Lazarou (1949-2013) of Galatas - Poros, Greece; an everyday hero, a kind, smiling and honourable person who gave everything, including his life, for his two children. Lest I never disappoint him.

Ὅπως ὅταν
γυρίζεις ἀπ᾽ τὰ ξένα καὶ τύχει ν᾽ ἀνοίξεις
παλιὰ κασέλα κλειδωμένη ἀπὸ καιρὸ
καὶ βρεῖς κουρέλια ἀπὸ τὰ ροῦχα ποὺ φοροῦσες
σὲ ὄμορφες ὧρες, σὲ γιορτὲς μὲ φῶτα
πολύχρωμα, καθρεφτισμένα, ποὺ ὅλο χαμηλώνουν
καὶ μένει μόνο τὸ ἄρωμα τῆς ἀπουσίας
μιᾶς νέας μορφῆς.

Πόρος, «Γαλήνη», 31 τοῦ Ὀχτώβρη 1946,
Γιώργος Σεφέρης, «Κίχλη».

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF PHYSICAL AND APPLIED SCIENCES
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Doctor of Philosophy

THREE ESSAYS IN INTERNATIONAL ECONOMICS

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Are transport markets and associated costs important for international trade? To the present day there is a sparse and fragmented literature pointing towards an affirmative answer. This Thesis reinforces such opinion by accounting for transport markets in general equilibrium models of trade, and providing empirical evidence on the impact of determinants that explain casual trade-and-transport related phenomena. The outcomes of the Thesis promote policy and/or investment activism in developing countries, due to the gains from trade lost to excessive transport costs. Two particular observations are investigated:

i) When and why should a transport hub emerge? Using a simple trade model of monopolistic competition with representative firms incorporating network theory, the determinants governing optimal network formation become the level of transport costs, increasing returns in transportation and centrality. Empirical deduction supports that exports increase more on average if a shipping route passing through a hub is selected relative to a direct route, following a reduction in variable trade costs. Thus geographically disadvantaged countries that absorb high transport costs can ameliorate these by trading via a hub.

ii) Are tariffs and shipping prices complementary? By not assuming this interaction, standard trade models of representative and heterogeneous firms are unable to identify by decomposing the direct and indirect -that is, via adjustments in transport technology- effects of trade liberalisation, resulting in observing large elasticities of import demand. Invoking a model of monopolistic competition with heterogeneous firms that trade using transport services operating under increasing returns, it is the presence of the latter that amplifies the response of trade volumes to tariff declines. Yet transportation may also dampen such responses, for the shipping price is a function of the factory price of the good and a markup. The empirical experiments provide support to such propositions.

The last chapter is distinct and deliberates on the importance of modeling financial networks that represent real world transaction systems relative to abstract artificial topologies. It is found that the international network of financial exposures exhibits characteristics that are congruent with robust-yet-fragile networks. Employing a common model of contagion illustrates how the robust-yet-fragile network structure absorbs defaults by peripheral countries however becomes susceptible to default cascades when combinations of peripheral countries or a financial centre collapse.

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Declaration of Authorship

I, Nicholas-Joseph Lazarou , declare that the thesis entitled *Three Essays in International Economics* and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission

Signed:..

Date:...

Acknowledgements

Dear Reader,

Please take note of some important and special people who have helped me in various ways over the past four years; for it is without whom this dissertation could not have materialised. I shall always be grateful to them.

Thank you my dearest Father Totos, Mother Christine, Louise (Louby) for the constant support, understanding and the excellent meals we shared together (except for when Louby cooked!), the laughter, the love, the summer and the arguments too! Thank you Özlem Gürses for the lovely moments and the traditionals! Thank you my remarkable friends, the fantastic Dafni Papoutsaki, Maria Kyriacou, Panagiotis Giannarakis, Aysegul Bugra, brothers Carlos Pineda Bermudez and Omar De La Riva, Jason Hilton, Elif Kara, Luis Pinedo, Dilek Yildiz and Serhat Ulas, Melike and Ufuk Alper, Ioanna Magklassis, the shining star Mauro Testaverde for all his advice, Andres Luengo, Marcos Gomez, Qi Zhang, Derya Tas ("Me don't know!"), Billur Aksoy, Rossella Icardi, Rachel Bennett, Megan Ledger, Philippa Waterhouse, Katherine Harris, Matt Ryan, Yahia El-Hobarty, Federico De Luca and Merche Burgos, Konstantina Iliadi, Angela Luna Hernandez, Margarida Cheung Vieira, Rebecca Vassallo, Joe Viana, Michael Kearns, Kate Bech, Lucasz Prochownik, Jana Farrugia-Sadeh, Dario Vignali, Zeshan Yousuf, Steffi Sesuraj, Jess Savage, Olli and Rita Jokiaho, Giorgos Dritsakis. Thank you my dear friends of the 2008-2009 MSc Finance and Economics cohort my brother Sotiris Blanas for the fantastic comments, Orphe Divounguy, Dr. Mohammad Mousavi, the Royal Highness Valeria Zakharova, Paola Di Casola and Spiros Sichlimiris who are getting married this July, Egle Margeviciute, Sharath Meppallil and Marta Cecconi. The fine ladies and gentlemen on the third floor, Panos Nanos for the support and encouragement, Manos Mentzakis, Tassos Magdalinos, Alex Mennuni, Carmine Ornaghi, Emanuela Lotti, Francesca Rossi, Jackline Wahba and Héctor Calvo Pardo. In the USA, thank you Anne, Nicole, Alexander, Peter and Melina, Sandie and Reeve, Eliza and Wyatt, Bev at the Norwich community breakfast for keeping me well fed.

In Greece, thank you my brothers and sisters, best man Babis and Lambrini, Konstantina and Antonis and little Apostolos, Mariliza and Kostas Tsichlis, Angelos Antonakas and Persefoni Georgiou, Nick Gkoumas, Paraskevi Thanopoulou, the two cats Natasa and Marietta Asik (technically in Belgium!), Vassilis Sideris and Maria Daskalaki, Vassiliki Giannakou, Giannis Sofogiannis, Akis Lazaropoulos, Christos Mavrodimitrakis, Eleni Simoudis, Lina Syriopoulou, everyone at Meandros Lines S.A. and Father Seraphim. To the Greek MSc alumni who became friends for life, I say thank you Stratoula Charitidou, Ntina Athanasiou, Giannis Sdrolias, Ermioni Ouranou, Christina Giagka, Margarita Georgousopoulou and "Manolis Faikopoulos", Michalis Thomas, Michalis Fragkioudakis.

Thank you my family, beloved grandma Esme Atherton, Janice and Charles, Thomas and Helen and Jimbo, Emma and Matthew and Lyra, Gareth and Jane, Poppy and Takis, Xanthi and Sofia, Giannis and Efi, Giannis and Dimitra (for the constant transeuropean supply of olives!), Andreas and Sasa, Tassos and Poppy, Dimitris and Georgia.

Thank you to the Department of Economics at the University of Southampton and the Economic and Social Research Council for awarding me with a scholarship to pursue this Thesis.

Lastly and importantly there are two people whom I deem very special: Thank you my remarkable Supervisors Héctor Calvo Pardo and Jackline Wahba. Your constant support, encouragement (and demands!) to learn and advance resulted in the chapters that follow. Through them, I was acquainted to Luca Opromolla who I thank dearly for his advice. They helped me go to Dartmouth College of all places! And there I warmly thank Andreas Moxnes, Robert Johnson, Daniel Rockmore and all the staff of the Economics Department for giving me the opportunity to study harder and learn. From the wider academic community thank you Costas Arkolakis for the ideas, Dimitra Petropoulou for the encouragement and participants at all conferences whose comments have been duly considered when drafting the chapters.

Thank you all from the bottom of my heart for these groundbreaking years.

Nomenclature

CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CES	Constant Elasticity of Substitution
CIF	Cost Insurance Freight
EU	European Union
EU 15	EU 15 area countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom
FOB	Free On Board
FTA	Free Trade Agreement
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
HS	Harmonised System
IMF	International Monetary Fund
IV	Instrumental Variable(s)
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
TRAINS	Trade Analysis and Information System
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US(A)/(D)	United States (of America)/(Dollars)
WITS	World Integrated Trade Solution
wrt	with respect to

Unless specified, transport costs, transport prices and shipping prices are equivalent terms.

Chapter 1

Introduction

This chapter presents an overview of the implications of modelling approaches to transport costs in the context of international trade and development. An extensive survey of the theoretical and empirical literature is undertaken and stylised facts about transportation and transport costs are exhibited. The purpose of such a chapter is to signify the aim of the doctoral thesis and to identify its position in the international trade and economic development literatures. The contents are organised mainly on the time dimension. Section 1.1 documents the evolution of the trade literature incorporating an ad valorem transport cost, or "iceberg" cost as it is customary known, and deliberates on empirical findings. Section 1.2 discusses the studies challenging the iceberg cost assumption by introducing alternative functional forms with corroborating evidence. Section 1.2.1 illustrates the transport sector and its market structure; the evolution of transport costs over time; and their relative importance with regard to trade costs for economic development. The chapter concludes by delivering the aim and position of this doctoral thesis in the extant literature.

1.1 A history of the iceberg cost of international trade

The fundamental modelling tool of trade costs in international trade is referred to as the "iceberg" cost. This term was first introduced in the works of Samuelson (1952, 1954) in order to study how the terms of trade alter when there occurs a unilateral transfer payment in the presence of transport costs rather than assuming a transport-free world. The cost was introduced as a payment measured in units of the traded good where "*to carry each good across the ocean you must pay some of the good itself. Rather than set up elaborate models of a merchant marine, invisible items, etc., we can achieve our purpose by assuming that just as only a fraction of ice exported reaches its destination as unmelted ice...*". By using this construct Samuelson is able to prove that a unilateral payment to a recipient country shifts the terms of trade in favour of the paying country rather than the opposite case, which holds when transport costs are assumed non-existent.[1]

The combination of iceberg costs and the model of trade with homogeneous firms -that is, firms which are characterised by the same marginal cost and thus output- engaging in monopolistic competition pioneered by Dixit & Stiglitz (1977) and Krugman (1979) shaped much of the trade literature that came to be known as the "*unfortunate phrase of New Trade Theory*" (Krugman 2009). At its heart, the literature explained how technologically identical countries specialise in producing different products, giving rise to trade as consumers sought variety. The intensity of transport costs and factor mobility subsequently led to models of "*New Economic Geography*", where a trade off between transport costs and the level of fixed costs associated with manufacturing production would determine concentration of production in a particular location, endogenising market size: If economies of scale are large in the presence of low iceberg costs, agglomeration effects are created, provided production inputs are mobile across locations. The locational choice is arbitrary and can arise as a function of initial conditions or historical incidence.

More specifically, Krugman (1980) showed that in the presence of iceberg transport costs and factor immobility, the larger of two trading countries will have, ceteris paribus, the higher wage. Firms will specialise in the production of a set of varieties for which the domestic market is large, giving rise to the *home market effect*: Locations with a relatively larger home market have more than proportionately larger relative number of firms. Therefore exports of a particular class of goods occur as an outcome of firm specialisation stemming from the size of the home market.[2]

In Krugman (1991) the assumption of factor immobility is relaxed and factors are allowed to migrate to where their real return is highest. The level of iceberg costs and the strength of scale effects determine the distribution of economic activity that can form a core-periphery economy. The location of manufacturing production arises where relative demand for goods is high due to minimal transport costs. Peripheral locations are facilitated by the central manufacturing agglomerates. Demand for manufactured goods itself originates from the mobile agricultural and manufacturing production factors, hence the market will become larger where manufacturing production occurs. This gives rise to a circular causality however, since concentration of manufacturing production occurs where the market is large. The result is that historical incidence and initial conditions will be playing a fundamental role for determining the geographical location of the core and the periphery.

[1] A similar approach of measuring transport costs involved the consumption of grain by horses that transported the commodity. This setting was adopted by Von Thünen in 1826 and so it can be considered as a predecessor of the iceberg cost. See Chapter 4 of Fujita, Krugman & Venables (1999) for details.

[2] For an extension incorporating production of intermediate goods see Helpman & Krugman (1987).

The level of transport costs also determines the *hub effect*. In a three country world involving one asymmetry, concentration of production will take place in a location with better transport access than the other two in the presence of scale effects in manufacturing. The hub area then becomes self sustaining, a large home market coupled with supply of inputs which can be further reinforced if transport is perceived as an activity subject to increasing returns (Krugman 1993).

In terms of economic development, Krugman & Venables (1995*a*) add intermediate goods and yield an interaction with labour migration that leads to manufacturing agglomeration with firms becoming interlinked. Globalisation is shown to lead to uneven development since for a given trade liberating level of transport costs, manufacturing concentration offers a large market of intermediate goods, inducing their production. A greater variety of intermediate goods translates into lower costs of production for final goods leading to further concentration of manufacturing and so on. As transport costs decrease further, the world is organised into a core-periphery system where the return to factors is enhanced in the core by virtue of higher labour demand, causing a divergence in real wages to the expense of the periphery. In an empirical setting that entails a structural model of monopolistic competition incorporating iceberg costs, Redding & Venables (2004) show that the effects of economic geography, namely measures of domestic and foreign market access, depend crucially on the level of internal and external transport cost variation.

In the context of intermediate goods and iceberg costs, yet without assuming scale effects, Rossi-Hansberg (2005) studies the spatial distribution of production.[3] Specialisation is a product of the level of transport costs with complete specialisation occurring in a transport-free world as each country would trade the good solely produced in its boundary. As iceberg costs decrease, the gains from concentrating production in a location become smaller than the costs of shipping final and intermediate goods along an ordered line. An additional result is that the impact of border effects on the pattern of specialisation is further amplified in the presence of iceberg costs.

In parallel to the development of "*New Economic Geography*" in the mid-90's, an increasing body of empirical evidence utilising firm data consistently showed substantial heterogeneity in productivity even within narrowly defined industries. Exporting within a sector is a relatively rare activity, associated only with the most productive firms and is non-random suggesting a self selection into exports.[4] Trade liberalisation was responsible for generating reallocations of resources within narrowly defined industries raising

[3]The implication of the iceberg cost in a spatial setting of trade is also discussed in Krugman & Venables (1995*b*), Fujita & Mori (1996), Fujita, Krugman & Venables (1999).

[4]Examples of such studies are Bernard, Jensen & Lawrence (1995), Roberts & Tybout (1997), Clerides, Lach & Tybout (1998), Bernard & Jensen (1999). The exhaustive list of empirical evidence is presented in Redding (2010) and Bernard, Jensen, Redding & Schott (2012).

average industry productivity as less productive firms are forced to exit production altogether.[5] Hence a theoretical "*update*" was required in order to explain the above empirical findings as the assumption of firm homogeneity became insufficient. Melitz (2003) introduces firm heterogeneity in productivity to the model of monopolistic competition. The useful iceberg cost serves as the parameter which, together with the level of fixed costs, determines selection into exports and the reallocation of resources across firms within an industry.

The introduction of firm heterogeneity constituted a point of departure from *"New Trade Theory"* and two streams of theoretical settings emerged that helped explain the aforementioned observed empirical irregularities associated with homogeneous firms.[6] In Eaton & Kortum (2002), geographic barriers, heterogeneity in technology rather than productivity with firms producing homogeneous goods, led to specialisation in a multi-country Ricardian setting with the probability of shipping a good to a specific country being hindered by the iceberg cost. Bernard, Eaton, Jensen & Kortum (2003) utilise Ricardian differences in technological efficiency across firms and countries. Exporters and non-exporters of the same industry are separated by the iceberg cost as a criterion and firms engage in Bertrand, as opposed to monopolistic, competition. The distribution of markups is obtained within a country and then firms will select a markup that is proportional to their efficiency draw. The iceberg cost acts as a trade barrier rather than simply a transport cost. Low trade barriers translate into higher markups on average, implying export participation for the most efficient firms only.

Remaining on the issue of endogenous selection of markups, Melitz & Ottaviano (2008) use a linear demand system in a monopolistic competition setting with heterogeneity in productivity instead. Market size and trade exposure affects the toughness of competition leading to the selection of a markup. Exposure to trade forces the least productive firms to exit due to the presence of the iceberg cost, the level of fixed costs and increased product market competition. Aggregate productivity increases for the set of exporters and they charge lower markups the larger is the market they self select into.

Thomas Chaney extends the model of Melitz to provide an explanation for the determinant of self selection into exports[7] and of the export volume of each incumbent exporter.[8] The elasticity of substitution affects these two margins in the opposite way making new exporters, with lower productivity on average, more sensitive to the iceberg cost when competition is low. Incumbent exporters only increase their exports moderately and hence the market share for the set of new exporters is larger; the reverse holds true as

[5] Empirical evidence is presented in Roberts & Tybout (1991), Pavcnik (2002), Bernard, Jensen & Schott (2006) and Bernard, Jensen, Redding & Schott (2007).

[6] See Eaton, Kortum & Kramarz (2011) for unifying theory of the Ricardian and the monopolistic competition strands.

[7] The level of exports resulting from firms self selecting into exports is known as the extensive margin.

[8] Also referred to as the intensive margin.

the elasticity of substitution gradually increases. The extensive margin always dominates the intensive since the elasticity of substitution has no effect on the elasticity of trade flows with respect to the variable trade cost, namely the iceberg cost, and thus the prediction of the Krugman model of trade is overturned. The empirical counterpart to Chaney (2008) is Helpman, Melitz & Rubinstein (2008) who are able to estimate the levels of the intensive and extensive margins and confirm the existence of a bias in the gravity equation that did not account for the extensive margin.[9]

In Eaton, Kortum & Kramarz (2011) it is mentioned that market size may be correlated with firm entry yet they observe many small exporters in each origin. But this is inconsistent with the ability of only the most productive firms being able to pay the homogeneous fixed cost toward export participation. Arkolakis (2010) provides an appropriate explanation by introducing marketing costs. Exporting firms incur the marginal cost to reach a single consumer and an increasing marginal penetration cost to access additional consumers. Marketing may operate under increasing returns with respect to the destination market, is probabilistically observed by a consumer and is produced under Cobb Douglas bundles of labour from the origin and the destination. Heterogeneous firms can then derive the optimal market penetration decision that is decreasing in the iceberg cost and increasing in productivity. Focusing on the iceberg formulation, two implications arise in equilibrium. After trade liberalisation, the largest firms in a market grow at a positive rate. Small firms with low trade volumes grow with a higher rate when iceberg costs fall after their marginal cost to access additional consumers is found to increase slowly.[10]

In a specialised literature that was first developed in 1979 by James Anderson, linear expenditure models and trade separability are utilised in order to derive a gravity equation in general equilibrium. Traded goods and their varieties are aggregated to the country level due to the structure of similar traded goods on aggregate, identical constant elasticity of substitution preferences and a symmetric vector of trade costs, modelled by the iceberg cost. In an extension by Anderson & van Wincoop (2003), the first instance of a decomposition of the bilateral iceberg formulation into three groups by using the aggregate price of a good at the origin and destination is made: A group of exclusively bilateral trade costs, a group of trade costs affecting exclusively the origin and one that affects exclusively the destination. Three implications stem from such a decomposition. First, trade barriers are shown to reduce (size adjusted) trade between large countries more than between small countries. Second, that trade barrier reductions raise (size adjusted) trade within small countries more than within large countries. Thirdly, trade barrier reductions more than proportionately raise the ratio of (size adjusted) trade within a country rather than across countries if this country is smaller relative to its bilateral partner. Empirically their formulation corrects for the bias and

[9] Crozet & Koenig (2010) also provide an empirical validation of the Chaney model of trade.
[10] A dynamic setting of this model is presented in Arkolakis (2011).

identification issues that were observed with traditional gravity equations that lacked a theoretical foundation. This is proved by an application toward solving the border puzzle of trade.[11,12]

A common theme among all the above studies is that the iceberg cost has received little or no attention with regards to its validity and functional form.[13] Whilst the evolution of trade theory necessitated the alteration of production technologies, a change from competitive markets toward imperfect competition and heterogeneity in productivity, the iceberg at its core has remained unchanged for the last 60 years. One could argue that trade costs are small and so do not necessitate complicated modelling techniques that would abstain from the main element of study. Yet trade costs are not uniform and are large as Anderson & van Wincoop (2004) state. Based on US data[14] they are able to infer that "representative" trade costs for industrialized countries is in the region of 170 per cent (tax equivalent). 21 per cent of this figure is allocated to transport and transit related costs, 44 per cent are attributed to border-related trade barriers, and 55 per cent concern retail and wholesale distribution costs. The opinion expressed throughout this thesis is that the modelling simplicity of the iceberg transport cost should not be taken lightheartedly. This review now extends to cover the studies that challenge the functional form of the iceberg cost, presents facts regarding the size and type of transport and trade costs, and surveys the methodologies that adopt alternative functional forms to capture the stylised facts about transportation and its costs.

1.2 The functional form of the iceberg cost and transport costs

The destination price of a good or *C.I.F.*[15] price encompasses in ad valorem terms the set of *all trade costs* between origin and destination. These costs are a multiple of the

[11] The finding by McCallum (1995) where trade between Canadian provinces is 2,200% times the trade between US states and Canadian provinces, when distance and province/state size are controlled for.

[12] For an extension incorporating the incidence paid by producers and consumers see Anderson & Yotov (2010). For an exhaustive treatise of trade costs and empirical applications see Anderson & van Wincoop (2004) and Anderson (2010).

[13] The following note by David Hummels provides scepticism on the functional form of the iceberg cost: ***Transportation Costs and Adjustments to Trade.***

[14] They are not clear however as to the source of the data.

[15] C.I.F., "Cost, Insurance and Freight" henceforth *cif* is the INCOTERMS rule wherein "the seller delivers the goods on board the vessel or procures the goods already so delivered. The risk of loss of or damage to the goods passes when the goods are on board the vessel. The seller must contract for and pay the costs and freight necessary to bring the goods to the named port of destination. The seller also contracts for insurance cover against the buyers risk of loss of or damage to the goods during the carriage. The buyer should note that under cif the seller is required to obtain insurance only on minimum cover. Should the buyer wish to have more insurance protection, it will need either to agree as much expressly with the seller or to make its own extra insurance arrangements." (Source: INCOTERMS 2010)

factory price or $F.O.B.$[16] price of the commodity that is traded (Feenstra 2004) and are commonly perceived in the literature as loglinear (Anderson & van Wincoop 2004). Since the iceberg cost is an ad valorem measure, the elements of the set enter also in ad valorem terms. These elements can be geographical and cultural differences and transport costs that are uncorrelated with each other.[17] Hence one can summarise in ad valorem terms all finite trade barriers between an origin i and a destination j that are incorporated in the iceberg cost as

$$\tilde{\tau}_{ij} = \text{border}_{ij}^{\beta_1} \times \text{language}_{ij}^{\beta_2} \times \text{cultural affinity}_{ij}^{\beta_3} \times \text{transport costs}_{ij}^{\beta_5} \times \ldots \Rightarrow$$

$$\tilde{\tau}_{ij} = \prod_{n=1}^{N} \left[t_{ij}^{n}\right]^{\beta_n}$$

where $\tilde{\tau}_{ij}$ is at least unity, as the most common approach to modelling the iceberg is to assume that a quantity of goods greater than unity must be shipped in order for one unit to arrive at the destination.[18] Consider now the element of transportation. Due to lack of appropriate functional form for the transport sector[19] in the international trade literature, the barrier posed by transport costs is normally approximated by the distance between origin and destination (Disdier & Head 2008) and thus is uncorrelated with all other trade costs. By assuming this proxy one is abstaining from the many implications of the organisation and market structure of the transport sector.[20]

If transportation is perceived as a produced service then transport costs should be regarded as an additive component of the *cif* price of the good and not therefore as an iceberg component: According to Irarrazabal, Moxnes & Opromolla (2014) the shipping price comprises of a constant charge per product unit transported and a percentage charge that is associated with insurance.[21] We can thus write the *cif* price for one unit of a particular traded commodity as

$$p_{ij}^{cif} = p_{ii}^{fob}\tau_{ij} + f_{ij}$$

where the iceberg component $\tau_{ij} > 1$ does not incorporate transport costs f_{ij} since they are decomposed into the per unit element. The iceberg assumption fails when one

[16]F.O.B., "Free On Board" henceforth *fob* is the INCOTERMS rule wherein "the seller delivers the goods on board the vessel nominated by the buyer at the named port of shipment or procures the goods already so delivered. The risk of loss of or damage to the goods passes when the goods are on board the vessel, and the buyer bears all costs from that moment onwards." (Source: INCOTERMS 2010)

[17]For an exception to the rule see Djankov, Freund & Pham (2010) for the time to export barrier of trade requiring instrumentation to account for the endogeneity between high export volumes within countries that could improve or deteriorate trade faciliation and export times.

[18]See for example Melitz (2003).

[19]See Lugovskyy & Skiba (2010) and Lugovskyy & Skiba (2011) for a validation of this statement.

[20]The next section and Hummels (2007) present an overview of the transport sector.

[21]Irarrazabal, Moxnes & Opromolla (2014) consider estimating the complete set of additive trade costs such as distribution costs, transport costs and non-ad valorem duties. For example 18.9% of United States imports that correspond to 3.4% of non-agricultural goods are subject to non-ad valorem duties which are purely additive trade costs.

attempts to measure the ad valorem change in prices: Taking the ratio of prices we obtain

$$\frac{p_{ij}^{cif}}{p_{ii}^{fob}} = \tau_{ij} + \frac{f_{ij}}{p_{ii}^{fob}}.$$

If the shipping price is perceived as a constant percentage c_{ij} of the *fob* price, then the ad valorem percentage change would become $\frac{p_{ij}^{cif}}{p_{ii}^{fob}} = \tau_{ij} + c_{ij}$ which can be perceived simply as an additive scaling constant to the iceberg component (see Hummels & Skiba (2004)). This constant will tend to inhibit trade more if it is a large fraction of the *cif* price, implying the *fob* price of the commodity is relatively low, rather than if it only comprised a small fraction of the total value of the commodity. However it is a common presumption that the value of commodities may be associated with the cost of handling or the insurance component or the presence of a transport markup making the shipping price a function of the *fob* price. Given that transport firms operate using a known and characterised cost function, the optimal transport price will be a function of the marginal cost of transport, mc_{ij}.[22] Denoting $f_{ij} = mc_{ij} \times \left[p_{ii}^{fob}\right]^{\beta}$, the *cif* to *fob* price ratio of the good will become

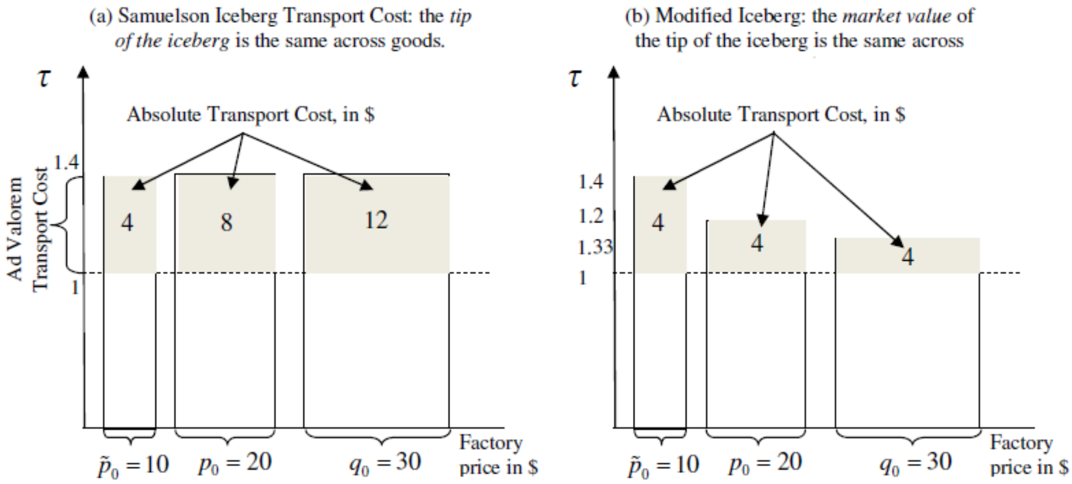
$$\frac{p_{ij}^{cif}}{p_{ii}^{fob}} = \tau_{ij} + mc_{ij} \times \left[p_{ii}^{fob}\right]^{\beta-1}$$

where if $\beta \neq 1$ then the *fob* price will play an important role in the determination of the *cif* prices. If $\beta = 0$ then the expression is an additive scaling constant to the iceberg cost as previously. Hummels & Skiba (2004) find that the elasticity β is significantly different from unity at around 0.6, which results in confirmation of the Alchian and Allen hypothesis and a rejection of the iceberg component at least for transport costs.[23] Irarrazabal, Moxnes & Opromolla (2014) find estimated values of f_{ij} to be 14% relative to the median price times the iceberg cost, hence the additive component becomes quantitatively important. Hummels, Lugovskyy & Skiba (2009) employ additive transport costs to confirm that market power in shipping explains the variation of shipping prices across destinations and goods. It is concluded that by simply using distance as a proxy for transport costs in a pure iceberg setting omits a quantitatively important component of transportation that is correlated with the factory price of the good, warranting a re-evaluation of the iceberg component and the implications for trade in general. This operation however may result in loss of the functional simplicity of the iceberg assumption and yield a number of potential modelling and identification issues that will be addressed toward the end of this section.

[22] See Limao & Venables (2001), Clark, Dollar & Micco (2004), Hummels, Lugovskyy & Skiba (2009) for the determinants of transport prices.

[23] The Alchian and Allen hypothesis states that any external costs increase the relative consumption of the higher valued commodity if these costs are an additive or per unit component of the final price of the good. If *value* is correlated with quality (as Hummels & Skiba (2004) show) then the Alchian Allen effect leads to increased trade of the relatively higher quality commodities.

Figure 1.1: Iceberg costs and augmented iceberg costs, source: Lugovskyy & Skiba (2010).



In the most recent cases in the extant literature, Lugovskyy & Skiba (2010) and Lugovskyy & Skiba (2011) introduce an augmented iceberg component in order to preserve the simplicity of the iceberg assumption in their theoretical model. The element of trade costs associated with transportation within a sector, has both ad valorem a_{ij} and specific s_{ij} components. Not considering the presence of any other trade costs b_{ij}, they assume a competitive market for transport. The shipping price then becomes

$$f_{ij,\phi} = 1 + a_{ij} + s_{ij}/p_{ij,\phi}$$

where the specific component, is dependent on the factory price of a commodity indexed by ϕ. Measured in units of the good, $f_{ij,\phi} - 1$ is the amount of commodity ϕ that is required by each transporter to carry one unit of commodity ϕ from origin to destination. As shown in Figure 1.1 reproduced from Lugovskyy & Skiba (2010), the left panel shows the iceberg cost that is a constant proportion of the factory price of the good. On the other hand the right panel shows the augmented iceberg cost where the same dollar value of transportation $a_{ij} + s_{ij}/p_{ij,\phi}$ is expressed in ad valorem terms $f_{ij,\phi} - 1$ relative to the factory price of the good.

By conducting this operation the authors can reconcile the functional form of additive trade costs with the analytical simplicity of the iceberg cost. In this regard they yield an analytical general equilibrium solution where the quality of a commodity decreases in the degree of "ad valorem-ness" of the transport cost which is unique for each destination and quality level and as previously mentioned depends crucially on the factory price of the good.

1.2.1 Loss of tractability and identification issues

The iceberg assumption has the power to explain a range of trade phenomena by merely introducing frictions in a manner similar to ad valorem tariffs with no other particularly interesting interactions.[24] In homogeneous firm models of trade with assumed constant elasticity of substitution (CES) preferences, the elasticity of trade flows with respect to the complete set of iceberg costs $\tilde{\tau}_{ij}$, typically enters with magnitude $1-\sigma$, where $\sigma > 1$ is the elasticity of substitution. It is increasing, in absolute value, the more homogeneous the good becomes (i.e. when σ is high). In heterogeneous firm models of trade with CES preferences, the elasticity depends on the degree of firm heterogeneity γ of a sector which stems from the export participation decision of firms. Since each specific trade cost element enters with its own elasticity β_n identification issues are minimal in these two classes of models. Estimated coefficients can be analysed to determine the magnitude of σ and/or γ and β_n.

When transport costs are approximated by distance such that $f_{ij} = d_{ij}^{\beta_d}$, most researchers find an estimated coefficient ~ 1 (Chaney 2013*a*). Hummels (2001) decomposes the estimated coefficient and finds a value for β_d in the region of 0.3 and σ is approximately 3.3. Chaney (2005) finds for a low band of the elasticity of substitution values of σ averaging 2.13 and β_d being 0.11 at its mean value. For a high band of the elasticity of substitution the values of σ are 16.33 and $\beta_d = 0.62$ on average. Crozet & Koenig (2010) when taking into consideration the degree of firm heterogeneity find an average value of σ equal to 8.20 with average $\beta_d = 0.17$ and complementarity would ensure that the average γ for a sector is 10.76. In Limao & Venables (2001) the corresponding value for β_d is 0.21.

In studies where there is a per unit component in transportation incorporated in the presence of an iceberg cost, tractability becomes more difficult. The elasticity of exports with respect to the destination price p_{ij} now becomes $1-\sigma$ and the impact of τ_{ij} and the additive component f_{ij} cannot be observed in their levels. This occurs because the (absolute value of the) elasticity of exports with respect to the transport price f_{ij} becomes $\epsilon_{f_{ij}} = \epsilon_{p_{ij}} \times \frac{f_{ij}}{p_{ii}b_{ij}+f_{ij}}$, a variable scaling of the elasticity of import demand that depends on *i*) the level of the transport price (and hence the marginal cost of transport), *ii*) the iceberg trade cost vector b_{ij} and *iii*) the factory price of the good p_{ii}. The existence of additive trade costs acts as a dampening parameter to the elasticity of import demand. Introducing a simple example, if $\epsilon_{p_{ij}} = (\sigma - 1) = 5$ then there is a 5 per cent decrease in exports following a 1 per cent increase in the destination price p_{ij}. The presence of the additive component ensures a dampening effect, since the term is less than one, that would depend on the level of the additive component. If $\frac{f_{ij}}{p_{ii}b_{ij}+f_{ij}} = 0.5$ then the percentage decrease in trade resulting from a one per cent

[24] See note by David Hummels: ***Transportation Costs and Adjustments to Trade*** for a validation of this statement.

increase in transport prices is halved to $5 \times 0.5 = 2.5$. As the transport price rises the dampening effect becomes less severe and in the limit it approaches $\epsilon_{p_{ij}}$. On the other hand, when transport prices are a small percentage of the destination price, then changes in the former have relatively inelastic effects on exports. Yet how is possible to distinguish whether changes in trade flows occur through a change in iceberg or additive components of the destination price?

Hummels & Skiba (2004) identify the variation attributed to transportation by expressing factory prices per destination relative to the sectoral mean. The same applies for transport costs f_{ij}. In this respect the aforementioned elasticity β_d becomes approximately 0.255. And subsequently the factory price elasticity with respect to transport costs becomes 0.82. Their study implies that variation in shipping prices affects the *fob* price of the good leading then to "shipping the good apples out", a colloquial term for the Alchian and Allen hypothesis.

Hummels, Lugovskyy & Skiba (2009) take into consideration commodity prices that include a tariff. Their aim is to identify if the effect of a change on the optimal markup set by transporters depends on the price of the traded good. They uncover a positive correlation between tariffs and optimal markups by observing the effect of a tariff increase on the commodity's transport price. The additive element associated with the transport price becomes a lower percentage of the destination price because of a tariff increase and this subsequently increases the optimal markup set by the transport firm. The positive correlation between tariffs and shipping prices does not occur from the variation in the marginal cost of shipping but from the systematic relationship between tariffs and optimal markups. Using a two step methodology to compute the variable elasticity that is attributed to the additive pricing regime they find that $\beta_d = 0.23$ on average. While distance may be explaining a portion of the variation in destination shipping prices and hence *cif* prices, the variation in the shipping price is also positively correlated with factory prices: High priced goods have shipping prices that are 18-21% higher than lower priced goods.

In Irarrazabal, Moxnes & Opromolla (2014) changes in the elasticity of quantity demanded with respect to the producer price are considered. They propose that an increase in additive trade costs leads to a lower elasticity of the quantity demanded that is increasing in the producer price. Thus low priced firm products face larger declines in demand following increases in additive trade costs as opposed to high priced firm products even within narrowly defined sector-destinations as they empirically confirm. Aggregating across sectors and destinations the authors find that additive trade costs relative to the median factory price times the iceberg cost are 14 per cent. 95 and 88 per cent of the destination and product fixed effects that comprise the additive trade costs for each product-destination are significantly different from zero, giving rise to the quantitative importance of additive costs compared to an iceberg setting only. The welfare implications are also altered since multiplicative trade costs affect relative consumption patterns between the imported and domestic good while additive trade costs affect relative consumption across imported goods. Imposing an equal yield tariff revenue that can be collected either by imposing a multiplicative tariff or an additive tariff, they report a 50 per cent higher decline in welfare for the additive tariff relative to the complement.

Lastly, for the two studies[25] containing the augmented formulation of the iceberg cost, the ad valorem equivalent of the additive share of the transport price is approximated by taking the ratio of product specific effects to distance. They document that components of the costs of transport not related to distance play an increased role in the variation of prices of goods in the presence of long distances rather than short.

1.3 Stylised facts about the transport sector and transport costs

The works presented in the previous section assume a particular market structure for transportation under the modelling requirement of additive costs. The only exception is Hummels & Skiba (2004) where they just assume a charge that is positively correlated with the factory price of the good whilst perfect competition is assumed in Lugovskyy & Skiba (2010), Lugovskyy & Skiba (2011) and Irarrazabal, Moxnes & Opromolla (2014) and an oligopoly in Hummels, Lugovskyy & Skiba (2009). This section asks whether such assumptions are justified by conducting an overview of the transport sector's organisation. It is concluded that within each mode of freight transport there exist a number of differentiated markets and so a particular selection of market based on the modal choice becomes a necessity. When considering a market for transportation irrespective of its mode, a suitable candidate becomes monopolistic competition. Lastly, the implications of the transport sector and transport costs for economic development are portrayed.

Transport is one the most pervasive activities in societies and economies, existing as the means for the re-distribution and provision of goods for consumption between spatially differentiated places.[26] Through the transport sector goods and services acquire an added value: A commodity or a service may be of low marginal utility at the source of production and via transit to a destination where its marginal utility is higher it is perceived more valuable. The transit is undertaken by transport systems characterised by three ingredients, these being the mode of transfer[27], infrastructure and load, operating in three types of geographically categorised areas as summarised in Table 1.1.[28]

[25]Lugovskyy & Skiba (2010) and Lugovskyy & Skiba (2011).

[26]See Hoyle & Knowles (1998) and Blauwens, De Baere & Van de Voorde (2006) for a validation of this statement.

[27]For variations of the Eaton & Kortum (2002) model of trade incorporating a substitution between modes of transport using an iceberg cost see Lux (2011) and Harrigan (2010).

[28]See also (Blauwens et al. 2006, p. 21, 23; Stopford 2009, p. 50) for this categorisation.

Table 1.1: Modes of commodity transportation

Area	Mode	Infrastructure
Inter-regional	Sea	Ships
	Air	Planes
	Pipe	Fuel pipelines
Short-sea	Inland waterways	Ships, ferries, barges
Land	Road	Trucks
	Rail	Trains
	Pipeline	Fuel pipelines

Source: Combination of Stopford (2009, p. 50), Blauwens, De Baere & Van de Voorde (2006, p. 28), Mallard & Glaister (2008, p. 24).

In turn goods can be classified as being valuable and non-valuable, perishable and fragile. Non-valuable goods are normally transported in bulk and in large parcels using any of the above modes and taking advantage of economies of scale. When considering a perishable good the opposite occurs: The need to have the good delivered prior to its deterioration will involve smaller parcels, more sophisticated travel and usually a higher unit transport cost (Blauwens et al. 2006, p. 29; Stopford 2009, p. 55). The use of more than one transport mode for a flow of any classified parcel of goods from origin to destination is thus defined as intermodal transportation (Hoyle & Knowles 1998, p. 263).

The transport sector can be split into separate industries for each mode (Blauwens, De Baere & Van de Voorde 2006, p. 336) such as the shipping industry, the rail industry etc., which comprise firms that supply transport services specific to a modal choice responding to demand by shippers for transport of goods based on (Cole 2005, p. 9):

i. the physical characteristics of the goods,
ii. the price of transport,
iii. the relative prices charged by different modes or different operators,
iv. the speed and quality of the service.

Within each transport mode that is henceforth defined as an industry, the offered transport services can also be further differentiated based on the physical characteristics of the commodities carried. For example the shipping industry provides three distinct means of transport service: Bulk transport, specialised generalised cargo transport and liner transport accommodating carriage of respectively dry/liquid bulk parcels (coal, crude oil); specialised parcels (cars, forestry products); general cargo parcels (loose cargo, containers, pallets) (Stopford 2009, pp. 61-64).

It becomes then apparent that instead of having one transport market for the whole of the transport sector, shippers are confronted by highly segmented markets each having their own particular characteristics. Using data from Transport Statistics Great Britain (2010), commodities transported by modal choice display, via Table 1.2, the existence of segregated markets based on the mode of transport. Specifically, petroleum and coal products in Great Britain can be transported by Road, Rail, Waterway or Pipeline depending on the characteristics of each product.

Table 1.2: Domestic freight transport by mode 1999-2009, in percentages

Commodity/Mode	1999	2002	2005	2009
Petroleum products				
Road	7.50	7.54	8.50	9.09
Rail	2.25	1.74	1.85	2.65
Water	72.86	74.93	72.95	68.94
Pipeline	17.39	15.80	16.69	19.32
Coal and Coke				
Road	29.33	20.0	14.71	13.33
Rail	64.0	76.0	81.37	82.67
Water	6.67	4.00	3.92	4.00
Pipeline	–	–	–	–

Source: Transport Statistics Great Britain, 2010 (latest available).

The most suitable transport industry for domestic carriage of petroleum products for the United Kingdom is shipping, otherwise pipeline transportation may be preferred by shippers. For coal and coke products trains seem to be the usual modal choice followed by trucks. Fluctuations in the quantities carried by mode can either be a source of market fluctuations or a degree of substitution between modal choice. These measurements can be precise enough depending on the physical characteristics of the cargo. Yet when parcels become smaller and the unit value of the commodity increases, the picture becomes more blurry. The type and characteristics of each commodity are grouped under a generalised category such as containerised cargo, palletized cargo, loose cargo, refrigerated cargo, which can consist of a variety of goods transported by a common for all, transport unit (Stopford 2009, pp. 65, 67-68). Confirming this statement, when observing freight volumes carried domestically by air for the UK the identity of the cargo is omitted and only the quantity is reported: 49, 54, 67, and 42 thousand tonnes for the respective years of Table 1.2 (Transport Statistics Great Britain, 2010).

Focusing on one mode, this being international maritime transport, the volume of trade carried by differentiated transport types within this mode are:

The dominance of transportation of energy products comprising commodities such as petroleum, coal etc., is pronounced. Another observation is that the traded commodities can be carried either in bulk cargo parcels, specialised parcels, and general cargo parcels by transport services specific to the commodities' characteristics leaving little room for substitution between carriers (Stopford 2009, pp. 61-64).

Table 1.3: World seaborne trade by commodity groups, in percentages

Commodity	1995	2000	2005	2006
Energy	41.79	40.72	39.23	38.62
Metals	16.84	14.68	15.35	15.73
Agriculture	11.20	9.91	8.41	8.13
Containerised	7.39	9.60	12.34	13.06
Other	22.78	5	25.09	24.47

Source: (Stopford 2009, p.57).

1.3.1 Scale economies in transportation

Clark, Dollar & Micco (2004) characterise international maritime transport as a classic example of an industry subjected to scale effects. Scale effects do not only stem from the size of the vessel but also from the building materials[29] and port infrastructure. At the vessel level they are related to ship size and trade volumes, with the largest ships deployed on the most voluminous trade routes and vice versa as one observes in Table 1.4.

In accordance to the table, Clark, Dollar & Micco (2004), after accounting for endogeneity, find a negative elasticity of freight rates with respect to the quantity transported suggesting the presence of economies of scale; the same finding is confirmed in Hummels & Skiba (2004) who report "moderate" scale effects. The advent of containerisation assisted in expanding scale effects in maritime transportation contributing to and benefiting from the growth of world trade (see for example Figure 1.2). Hummels (2007) reports that the innovation of containerisation resulted in cost reductions at the port level such as port labour costs and the rental rate on unused capital attributed to waiting times.

Cost reductions are further observed on the sea leg of the journey where larger vessel size accounts for a reduction in the price per tonne-mile. Yet with scale effects, come necessarily large fixed capital costs which have prevented the widespread adoption of containerisation especially in developing countries. Containerisation was first introduced in the 1960's in capital intensive developed countries. Trade routes amongst such countries are usually denser. In labour intensive economies, which can be associated as being developing, the capital cost for port infrastructure is relatively higher and the benefits of containerisation were slow to emerge (Levinson 2008, Bernhofen, El-Sahli & Kneller 2013). Hummels (2007) concludes that containerisation has significantly reduced maritime transport costs yet this effect might not be immediately apparent due to relative increases in other input factors such as rising fuel costs and increased markups.

[29]See Kalouptsidi (2011) for a dynamic model of industrial organisation involving shipbuilding.

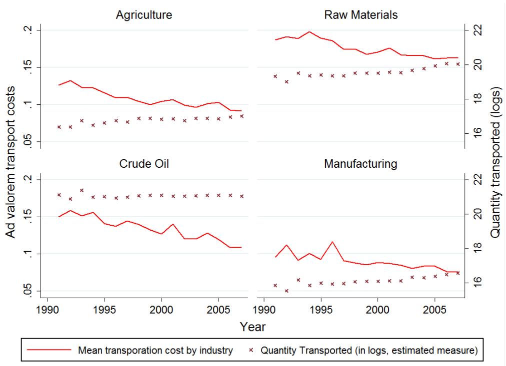
Yet it is the very introduction of containerisation that spurred globalisation according to Bernhofen, El-Sahli & Kneller (2013). They report a 700 per cent cumulative average treatment effect over a 20 year period from the adoption of the container among developed trading countries, with this estimate reduced to just above a third of its value when restricting the sample to the complement case. The positive effects of containerisation are much larger than those of free trade agreements which have a cumulative average treatment effect of 45 per cent and the General Agreement on Tariffs and Trade membership standing at 285 per cent.

Table 1.4: Distribution of oil carrier size across routes, in 1000's metric tonnes

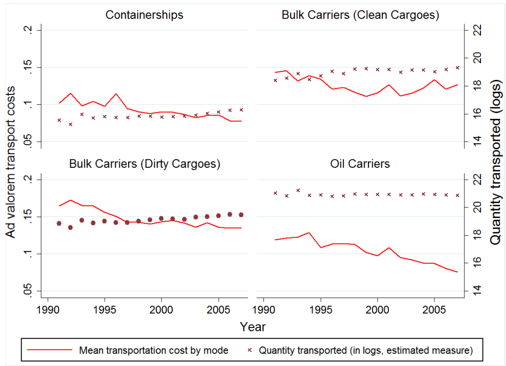
	Persian Gulf	W. Africa	N.W. Europe	Mediterranean	Indonesia	Caribbean
Japan	200					
Korea	200					
Europe	200					
Caribbean & ECNA	200	100-160	70-100	<50		70-100
S. Africa	200					
Mediterranean				100-160, 70-100, <50		
N.W. Europe		100-160	70-100	70-100		
E. Asia					70-100	
ECNA and Gulf of Mexico						<50

Source: UNCTAD Review of Maritime Transport, 2011. Vessel sizes are expressed in 1,000 metric tonnes. Table 1.4 represents the benchmark routes and ship sizes for which freight rates are fixed. ECNA stands for the East Coast of North America.

Figure 1.2: Japanese exports to the US 1991-2007, source: *OECD, Maritime Transport Costs Database* (2010)



Breakdown by type of goods



Breakdown by transport mode

With regards to scale effects in port infrastructure, Clark, Dollar & Micco (2004) find negative coefficients for the elasticity of transport costs with respect to port efficiency. They report an increase in containerised maritime shipping costs that is equivalent to an additional 5,000 km to the destination for a decrease in port efficiency from the 75th to the 25th percentile. In Limao & Venables (2001) the same reduction in port infrastructure accounts for an increase in transport costs that is equivalent to an extra 3,466 km to the destination.[30]

According to Hummels (2007), 99% of the world's trade by weight is carried by sea. The combination of scale economies in maritime transport and in port infrastructure made possible by the advent of containerisation induced the creation of hub and spoke configurations whereby export distribution is primarily defined by the cost saving size of the vessel and not necessarily via the closest distance. Hence, larger ships operate amongst the denser trade routes, whilst smaller ships deliver the quantity demanded to and from the major intersection ports. This organisation of trade distribution is a simple form of a network. In line with Hummels (2007), Hendricks, Piccione & Tan (1995) are of the opinion that ingredients such as exercise of market power together with the freedom of setting prices and routes, leads also airlines to set their optimal network formation, one that minimises total transport costs constrained by import demand.

The hub ports that emerged as a product of containerisation were not necessarily associated with facilitating supply of exports to cater for domestic import demand, but rather could be outcomes of geographical advantage and concentration of production that facilitate transit towards a final destination (Krugman 1993). Hence historical incidence,

[30]Levinson (2008) mentions that the expansion of port and ship capacity was driven by the same determinant: The demand for lower cost per container. He also mentions, based on World Bank figures, that if Peru had port management as effective as Australia's, foreign trade -subject to unconstrained demand- could increase by 25 per cent. The determinants of port infrastructure are discussed in Clark, Dollar & Micco (2004) and Abe & Wilson (2008). For the role of infrastructure in export facilitation see Djankov, Freund & Pham (2010), and Behar & Venables (2010).

Table 1.5: The world's largest container ports, by container throughput

Port	1990	2008
Singapore	5.21	29.91
Shanghai	0.5	27.99
Hong Kong	5.1	24.49
Shenzen	0	21.41
Busan	2.3	13.45
Dubai	1.1	11.82
Rotterdam	3.7	10.8
Qindgao	0.1	10.32
Hamburg	2	9.73
Kaohsiung	3.5	9.67
Antwerp	1.6	8.66
Port Klang	0.5	7.97
Los Angeles	2.6	7.85
Long Beach	1.6	6.48
Tanjung Pelepas	0	5.6
New York	1.9	5.26

Source: Levinson (2008) which has been augmented to include the latest figures based on the UNCTAD Review of Maritime Transport, 2011. Numbers are in Millions of Twenty Equivalent Units (TEU).

interregional trade and globalisation all play a role in the development of these formations leading to hub ports achieving "massive" sizes as suggested in Levinson (2008). Table 1.5 presents the major containerised ports of the world arranged by the number of containers handled in the last year of measurement. An interesting finding is that the total number of containers handled by these ports alone in 1991 is approximately equal to the global containerised trade volume, whilst for 2008 it is 54 per cent higher than the volume of global containerised trade standing at 137 million TEU's. This converts to about 1.3 billion tonnes of traded goods which is nearly 25 per cent of the world's non-liquid traded goods. Assuming that the weight/TEU ratio remains constant then total throughput of these ports alone can be calculated to 35 per cent of the global trade in dry goods.

The general consensus in the aforementioned literature is that technological innovation reduces transport costs or creates positive externalities such as intermodal transportation, yet what are the impacts on the growth of world trade? The principle study answering this question is Baier & Bergstrand (2001) who, for the post second world war period, attribute the 148 per cent growth to three factors, income growth (explaining 68 per cent of the growth), trade liberalisation (38 per cent) and transport costs (8 per cent). In an important paper explaining the implications of adverse transport costs for developing countries, Radelet & Sachs (1998) state that if transport costs double, annual growth is reduced by about 0.5 per cent per annum.

1.3.2 How responsive is demand for transport

Various modes of transport may comprise mode-specific firms that trade in segmented markets and responding to mode-specific demand (Mallard & Glaister 2008, p. 69). A survey of studies on demand for transport elasticities at the aggregate level across modes (with elasticities available also at a more disaggregated level within modes), reveals that demand for transport services is inelastic (Oum, Waters & Song 1990, p.ii).[31] All modes except airlines, the costliest modal choice per transport unit, display inelastic demand due to the fact that transportation is perceived as a derived demand (Oum, Waters & Song 1990, p. 13). As to the degree of substitution between modal choice for a selected sample in time it appears that road and rail transport as well as road and inland waterways are complement services whilst rail and inland waterways are substitute services (Mallard & Glaister 2008, p. 59).

Table 1.6: Elasticity of demand for transport, commodities

Mode	Range	Mean
Rail	0.40 - 1.20	0.80
Road	0.70 - 1.10	0.90
Air	0.80 - 1.60	1.2
Inland Waterway	0.74 - 0.75	-
Sea	0.11 - 0.46	0.28

Source: Oum, Waters & Song (1990).

Table 1.7: Cross elasticity of demand for transport, commodities

Mode	Range	Mean
Rail-Road	-0.10 to +0.14	+0.02
Road-Rail	-0.88 to +0.13	-0.375
Rail-Waterway	-0.15 to +0.20	+0.025
Waterway-Rail	-0.61 to +0.86	+0.125
Road-Waterway	-0.23 to +0.03	-0.1
Waterway-Road	-0.12 to +0.13	+0.05

Note: Aggregate figures for Canada are for selected years between 1950-1974. Source: Oum, Waters & Song (1990).

[31]The authors suggest caution to the figures representing inland waterway and ocean transport due to insufficient studies.

1.3.3 Market structures for transport modes

A key finding of this analysis is the inability to group the various transport modes under one market. Each transport mode and differentiated transport means under a specific mode, may have a distinct market with its own characteristics. Taking into account European countries across modes, it is observed that air transport within countries is characterised by perfect competition, with exceptions for some countries where monopolies and oligopolies are present. Concerning inland navigation, competition is also observed with the same applying for short sea shipping and some small cases of monopoly and monopolistic competition. Lastly road transport almost entirely operates under perfect competition in the E.U. (Blauwens, De Baere & Van de Voorde 2006, pp. 336-341).

By taking a global cross section of a specific mode, this being maritime transport, differentiated products are traded in segregated markets: Concerning bulk cargoes characterised by homogeneity, firms compete and are price takers (Mallard & Glaister 2008, p. 102), while the more heterogeneous a good becomes, a differentiated shipping service is required for its transportation and in this case firms appear to be exercising some magnitude of market power (Mallard & Glaister 2008, p. 97; Hummels et al. 2009, p. 50).

This may not be applicable for rail transportation where differentiated services may not be possible as goods are more homogeneous and the large infrastructure costs require monopolistic entities with some exceptions where competition is present (for example the UK) (Oum, Dodgson, Hensher, Morisson, Nash, Small & Waters 1997).

The existence of different modes of transport for carriage of goods requires the transport market to be segmented into mode-specific markets and a shipper may combine any mode of transport based on the degree of complementarity for the transport of her goods from origin to destination resulting in intermodal transportation. Thus goods can, at different parts of the journey, be carried by a monopolist or be transported by a carrier who competes for supply of her services (Hummels, Lugovskyy & Skiba 2009).

The transport service is also characterised by differentiated transport modes and in certain occasions further product differentiation within each mode (Stopford 2009, p. 50, 53). The existence of a degree of substitution between modes and within modes followed by the dominance of competitive markets for the majority of transport services in a number of countries observed in this analysis, leads to the following proposition concerning a generalised way of modelling transportation services in international trade models:

That transport services are differentiated products produced by firms engaged in monopolistic competition. The existence of barriers to entry such as large capital costs required to set up a transport network for some industries, the presence of a multitude of transport firms (Mallard & Glaister 2008, p. 96-97), the exercise of market power in particular differentiated modes or the free entry and exit of firms in modes such as road transport, are characteristics of monopolistic competition. In addition, the existence of multimodal transport, straddling the different market structures to facilitate the carriage of a good from origin to destination links modes and different markets. Thus at the aggregate level only, this study concludes that when there is a requirement of modelling a transport sector in an international trade framework, that monopolistic competition as the market structure for this sector should be adopted. When a specific mode of transport is considered, more consideration is required regarding the market structure in which mode-specific firms operate.

1.3.4 Transport costs and economic development

On establishing the importance of transport costs for economic development, the role of transportation and its costs are highlighted in the context of the following characteristics: distance and remoteness, landlocked-ness, infrastructure and import/export facilitation.

A number of developing countries are plagued by distance and remoteness, an inevitable factor that inhibits income growth (Redding & Venables 2004): For example, an additional 1000 km of land transport appears to increase the cost by 1,380 US dollars whilst the sea equivalent is 190. Being a landlocked country increases transport costs by nearly twice compared to non-landlocked countries when multimodal transport applies (Limao & Venables 2001). Yet for lightweight goods per value, direct air transport is a viable cheaper option for these countries as Radelet & Sachs (1998) suggest.

Lack of funds and of attention deteriorates transport modes as well as infrastructure rendering them technologically outdated in developing counties (Amjadi, Reinke & Yeats 1996) and preventing such countries from participating in global production networks: A doubling in the deterioration of infrastructure results in a 32 per cent increase in transport costs which accounts for half the transport cost penalty that Sub-Saharan African economies are bearing. This effect causes a reduction in trade by 145 per cent according to Limao & Venables (2001). In Grigoriou (2007) who considers Central Asian economies, an improvement in infrastructure from the median to the 25th percentile can increase exports and imports by 6.5 per cent and 8.6 per cent respectively by virtue of lower transport costs.

The impact is extended also with respect to border costs and intra-country transport costs: As shown in Table 1.8 and Figures 1.3 and 1.4, when compared to the developed world, developing countries require 30 days and 1,200 US dollars more in intra-country transport costs, handling and documentation procedures to export a standardised cargo of goods. In order to import the same cargo, 38 days and an additional 1,600 US dollars are needed compared developed countries. Coupled with observing a wide dispersion of

Table 1.8: Time and costs to import and export

	Ten Developing Countries		Ten Developed Countries	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Export Time (Days)	39.00	24.50	8.70	1.64
Export Cost (USD)	2,240.30	1,484.00	1,014.20	279.43
Import Time (Days)	44.60	28.95	9.00	2.36
Import Cost (USD)	2,605.50	1,764.82	1,085.20	317.52

Source: *World Bank, Doing Business Data* (2010).

the aforementioned factors' costs in developing compared to developed countries, it is inferred that border costs, intra-country transportation and red tape also affect the cost of transport as Behar & Venables (2010) confirms. The level of these costs can even rival that of the actual transport cost as Radelet & Sachs (1998), Amjadi, Reinke & Yeats (1996) report: While clearance of a 20 foot standardised container in two studied countries was roughly 1,000 US dollars, the corresponding sea freight for Europe was 1,400 US Dollars.

Figure 1.3: Exporting time and costs

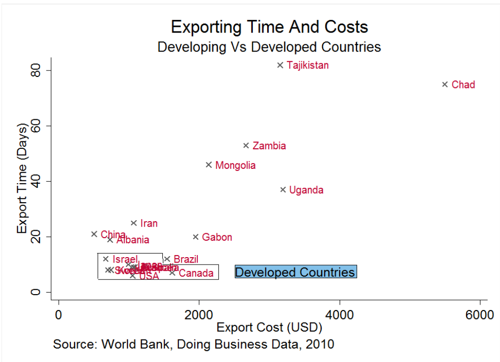
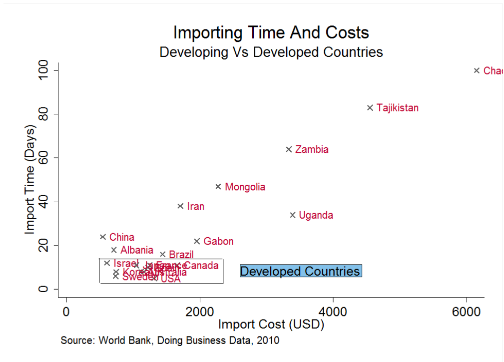


Figure 1.4: Importing time and costs



Lastly, the importance of transport costs for developing counties is also established by the fact that they have to absorb these costs so as to be in the position to penetrate foreign markets according to Amjadi, Reinke & Yeats (1996). The absorption hence prevents export-led development, reducing wages and inducing a welfare impact. Prevention of market access for developing countries translates to losses from trade due to their lack of proximity of about 68% lower per capita GDP on average for the sample in Redding & Venables (2004).

Since developing countries are usually geographically disadvantaged, transportation is one of the media through which this adversity appears, consequently increasing costs.[32] And as these costs, when taking Africa as an example, are far higher than tariffs based on the argument by Amjadi, Reinke & Yeats (1996) it becomes apparent that transport

[32] See MacKellar, Worgotter & Worz (2000) for a validation of this statement.

costs represent an important factor inhibiting economic development due to the deceleration of incentives for export-oriented investment: A significant amount of foreign exchange earnings is lost to transportation rather than investment.

1.4 Conclusion: The relative position of this thesis in the literature

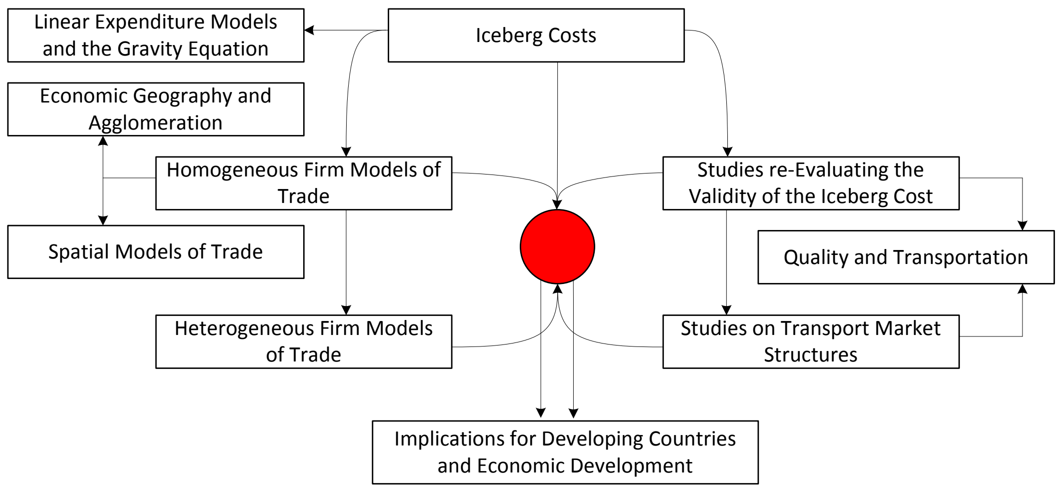
This introduction attempted to briefly present the studies containing theoretical applications of the iceberg cost of international trade and discussing the implications of such approaches.

Being the principal modelling tool of trade and/or transport costs in trade models and given the technological advances in transportation discussed in the previous sections, the main criticism is the lack of functional form for this simple tool. Across time and models it is invoked as a mere parameter to explain a plethora of trade related facts while the majority of the initial assumptions of trade models have experienced considerable evolution. Then, as Arkolakis et al. (2012) show under certain conditions, these models are led to similar welfare predictions pointing towards small gains from trade, which are governed by the share of income expenditure on domestic goods and the elasticity of imports with respect to trade costs. By allowing for functional forms of transport costs in trade models that capture some of the stylised facts discussed herein, the welfare predictions change. In the last 10 years, empirical studies with theoretical foundations such as Hummels & Skiba (2004), Hummels (2007), Hummels, Lugovskyy & Skiba (2009), Lugovskyy & Skiba (2010), Lugovskyy & Skiba (2011) and Irarrazabal, Moxnes & Opromolla (2014) have been challenging successfully that these ad valorem transport and trade costs are only the "tip of the iceberg": Trade costs modelled in the additive fashion reject the sole imposition of iceberg trade costs warranting a re-evaluation of their functionality and explanatory power in the associated literature. Yet these studies, with the exception of the second half of Irarrazabal, Moxnes & Opromolla (2014), who suggest that gains from trade are in fact larger than the standard trade models predict as the additive component is quantitatively important and omitted, are detached from the general equilibrium models of trade and form a separate strand of literature (Lux 2011).

This strand is based loosely on simple assumptions on the structure of the transport sector by consulting relevant transport industries' pricing behaviour or if not, mentioning this as a hurdle. In fact the lack of studies on the organisation of the transport sector and transport markets in international trade makes difficult the safe adoption of assumptions concerning the market structure or transport cost functions in a model of trade.

Taking into consideration the arguments laid within, the aim of this thesis is to bring together the strand of the literature incorporating a number of assumptions and functional forms concerning transport and trade costs with general equilibrium models of trade. By focusing on the particular characteristics of the transport sector, namely network structures, increasing returns to scale and correlation between transport costs and *fob* prices, the task is to examine the general equilibrium implications of such characteristics either by utilising homogeneous or heterogeneous firm settings as shown in Figure 1.5. The thesis complements the theoretical results with appropriate empirical corroborations or rejections of stated hypotheses. The outcomes of the thesis are directed toward developing nations after taking into consideration the substantial trade and welfare reducing impacts of the determinants of transport costs and transport infrastructure analysed in this chapter.

Figure 1.5: Positioning of the thesis in the literature



Chapter 2

Endogenous Hub Formations in International Trade

Hub locations such as Singapore have a ubiquitous role in facilitating international trade flows. Yet the reasons when and why should a transport hub emerge remain largely unexamined. Developing herein a simple trade model of monopolistic competition with representative firms incorporating network theory, the determinants governing the optimal network formation become the level of transport costs, increasing returns in transportation and centrality. Empirical evidence further suggests a 0.39% average increase in exports if a shipping route passing through a hub is selected relative to a direct route, following a 1% reduction in distance. Thus geographically disadvantaged countries that absorb high transport costs can ameliorate these by trading via a hub.

2.1 Introduction

Today 99% of the world's trade by weight and 90% of the volume of world trade is carried by sea (Hummels 2007, OECD 2008). Since the 1950's, contributing to the expansion of trade and globalisation lie technological advances in shipbuilding and port infrastructure that paved the way for greater scale economies in the carriage of goods, the reduction of labour and by correlation port capital costs, and most importantly the advents of containerisation and intermodal transportation (Hummels 2007, Levinson 2008, Rodrigue 2010, Rua 2012).

As a corollary these advances induced the creation of hub and spoke transport networks. Trade route distribution under such configurations is primarily characterised by the cost saving size of the vessel and not necessarily by the shortest distance, which affects trading volumes themselves. Hence larger ships operate amongst denser trade routes, whilst smaller ships deliver the quantity demanded to and from the major intersection ports for further transportation to the final destination (Krugman 1993, Hummels, Lugovskyy & Skiba 2009). Within this network, the emergence of particular hubs around the world such as Singapore and Rotterdam that facilitate transit toward the final destination either in the hinterland or to another port is the outcome of historical incidence, interregional trade, geographical advantage and concentration of production (Krugman 1993, Levinson 2008).

The contribution of this paper is to explain when and why will trading via a hub formation prevail and to yield empirical evidence of a hub port's ameliorating impact on trade flows. To this end, I employ the standard trade model with representative firms *á la* Krugman, whose connectivity with the final destination is assessed through costs and benefits using the symmetric connections network model of Jackson & Wolinsky (1996). It is found that when transport costs to a particular destination are high, firms instead of lowering their output or exiting this market, can choose to trade via a central hub provided there is a cost saving incentive - a benefit- of connecting indirectly to their trading partner, with the opposite holding true. I prove that the parsimonious model analysed herein is qualitatively equivalent to an alternative model of trade incorporating a transport sector operating under increasing returns, with the assumption that fixed costs associated with transportation can vary across destinations, thus reconciling the model(s) with the aforementioned stylised facts.

Using maritime transport routes the significant impact of hub ports at three levels of aggregation of export flows is confirmed empirically. This is achieved by comparing two alternative distance variables, one being the great circle capital distance, namely direct capital distance and the other being the distance between capitals after taking into consideration the sea leg of the route, namely indirect capital distance. For the latter I assign an indicator variable that serves to detect if a route passes through an exogenously defined hub port or not. Interacting the binary variable with indirect capital distance, it is found that the marginal effect of trading via a hub becomes significantly less in absolute value than the marginal effect of trading directly between capitals using the first measure of distance. This reflects a discount in the cost of transport due to the interaction. It is deduced that trading via a hub can have ameliorating effects as I document a 0.39% average increase in 2 digit level exports if a route passing through a hub is selected relative to a direct route, following a 1% reduction in distance.

Yet the hub binary variable acts also as a proxy for endogenous route selection and hence there is correlation with the independent variable. The endogeneity is addressed by undertaking a manual two stage least squares estimation instrumenting the endogenous interaction term with a constructed instrument stemming from the first stage (Wooldridge 2002, Ch. 18). The results are confirmed although I cannot rule out mispecification in the first stage due to the lack of functional form for the hub binary variable.

Surprisingly the question of when and why will a transport hub emerge has been widely ignored in the international trade literature. A plausible reason is the insufficient attention paid to the structure of the transport industry (Krugman 1993) combined with the lack of data on trade routes and transport costs. As a proposed explanation of hub formations, Krugman (1993) puts forward that production of commodities will be concentrated in a location from which all arrivals and departures have the lowest transport costs. The interaction between increasing returns to scale in manufacturing and transport costs thus leads to the emergence of a hub region. Hendricks, Piccione & Tan (1995), Starr & Stinchcombe (1992) and Oum, Zhang & Zhang (1995) propose that economies of density play a role as costs per passenger on an airline route decline with the number of passengers travelling on that route. Hub networks have higher traffic densities than larger networks with direct connections. The distance travelled is longer, but if economies of density are sufficiently large, the total costs of satisfying demands may be lower in hub and spoke networks than direct connections. Economies of density arise because of spreading fixed costs over a larger volume of passengers or declining marginal costs.

In comparison to the Krugman (1993) model of trade, locational advantage and the level of transport costs are the only determinants after controlling for country size in this model. Whilst concentration of production jointly with centrality may be of importance under air transport, the same need not apply for maritime transport. Some of the less developed regions of the world, such Panama or Port Said, obtain hub status conditional only on locational advantage. Concentration of production may then take place but is not a condition precedent. Further, it is not possible to develop a testable prediction for the existence of hub formations using Krugman's model of trade.

The implications of this study are directed towards developing countries as incumbent exporters have to absorb higher transport costs so as to be in the position to penetrate markets abroad. This situation prevents export-led development, reducing workers' wages and inducing a welfare impact (Amjadi, Reinke & Yeats 1996). Higher transport costs are attributed to geographical disadvantage and lack of proximity. Prevention of market access for developing nations translates to losses from trade of about 68% lower GDP per capita on average (Redding & Venables 2004). Therefore improvement of own and transit country infrastructure together with hub formations could make possible the amelioration of excessive transport costs (Limao & Venables 2001).

The paper contributes to a very scarce literature on the topic by perturbing the iceberg assumption in a trade model in order to account for effects arising from the structure of the transport industry. The importance of transport costs and specifically maritime transport costs has been documented in Hummels (2007) and Hummels, Lugovskyy & Skiba (2009). The prevalence of additive trade costs in addition to iceberg costs is highlighted in Irarrazabal, Moxnes & Opromolla (2014) and Hummels & Skiba (2004). Insight about the structure of the transport industry is provided in Hendricks, Piccione

& Tan (1995), Hummels, Lugovskyy & Skiba (2009) and Rodrigue (2010) whilst the impacts of, and substitutability between, transport modes on trade flows are presented in Lux (2011). Lastly, merging the network literature with international trade is a promising avenue for research: Chaney (2013*b*) illustrates that network formation can explain the heterogeneous ability of individual firms to access foreign markets for which productivity differences constitute only a fraction of this ability. In this important contribution to the literature, the (stable) spatial distribution of firm sales is the outcome of successful acquisitions of contacts arising from firms' remote and local searches. Hub formation in such a setting, while not explicitly discussed in Chaney (2013*b*), arises through random locational convergence of history dependent firm search paths, which is strictly reinforced over time in the absence of aggregate shocks. In my setting, hub formation is not based on historical dependence, but may create thereafter historical dependence, since the formation is governed by the routing choice of the transport sector based on geographical and infrastructural barriers.

The remainder of this paper is organised as follows. Section 2.2.1 provides the basic notions of economic and social networks that will be used in the model of section 2.2.2. The equilibrium is discussed in section 2.2.3 and the equilibrium empirical prediction for the existence of hub formations is described in section 2.3. The results are presented in the subsequent sections followed by concluding remarks.

2.2 Theoretical framework

2.2.1 Setup of the network

Consider a set of countries $K = \{1, 2, ..., k\}$ which engage or not in international trade through manufacturing firms. Countries can be *directly connected* or *directly linked*, if they have a direct trading relationship using no other intermediary country. Thus, a network G is defined as a list of pairs of countries $\{i, j\}$ that are directly linked to each other through a firm's trading decision. Each link can be represented as a *graph* $g \in G$. The existence of a *direct link* between countries i, j will be denoted as $g_{ij} = 1$, and $g_{ij} = 0$ will represent that there is no *direct link*.

Each *link* is associated with costs and benefits. These affect firms that choose to enter the export market in each particular country. If a direct link is formed by a firm then it must incur a cost c. There is a benefit $0 \leq \delta \leq 1$ associated with proximity or distance between i and j in the sense that the firm will prefer to trade to closer trading partners rather than more distant ones. The firm has the additional option to form an indirect link. Implicitly, there must already exist a direct link to another country for the indirect link to be feasible. The indirect link is formed without cost and receives only a pure benefit $\delta^{t_{ij}}$, where $t_{ij} \geq 0$ is the integer number of links between countries i,

j. This construction allows a firm in country i entering the export market to take into consideration their preference for trading to a close partner δ and associated cost c. It can also consider whether to connect directly to the destination country and incur this cost. Or alternatively, it can consider connecting indirectly. In the latter case it avoids the cost but receives a discounted benefit as the proximity decreases. The difference between the benefit of forming a link and the cost of a type of link is thus defined as:

$$v_{ij} = \delta^{t_{ij}} - c_{ij|ij \in G} \tag{2.1}$$

By convention we have $g_{ii} = 0 \Rightarrow c_{ii} = 0$ since $g_{ii} = 0$ is not a link in the network G and country i remains autarkic. Further, $t_{ij} = 0$ if there is no path that connects directly or indirectly countries i and j. An exposition of this construct is as follows. For $N = 3$ symmetrically placed countries assume that countries 1 and 2 are at the edges and 3 is in the middle. There can be two types of available networks. One network formation is direct links between all participants. Then the network is defined as $G = \{12, 21, 13, 31, 23, 32\}$. The second formation is an indirect link between 1 and 2 and direct links from and to country 3, such that $G = \{13, 31, 23, 32\}$. The net benefit term between countries 1 and 2 becomes for the case of direct links $v_{12} = \delta - c = v_{21}$. For the case of an indirect link between 1 and 2 we have: $v_{12} = \delta^2 - 0 = v_{21}$. The latter indirect link implies the existence of two direct links forming this particular connection: The link between 1 and 3 and the link between 3 and 2.

Countries are also characterised by their participation share in the network depending on the types of links they form. The network participation share will be perceived as the fixed cost associated with the network. While the participation share is not employed in the theoretical model, it will assist in the gravity equation specification and the parallel model of Appendix A.2 in lieu of the unobservable benefit of forming an indirect link. Denote the set of country i's direct connections in a network as $N_i(G) = \{i \neq j | g_{ij} = 1\}$. The cardinality of this set is $n_i(G)$. The size of the network is $n(G) = \sum_i^N n_i(G)$. The participation share of i in the network is simply $F_i = \frac{n_i(G)}{n(G)}$. To provide an example, consider the direct links network for the 3 countries. Country 1's set of direct connections is $N_1 = \{12, 13\}$ and the cardinality of the set is $n_1 = 2$. The total number of direct connections is 6, and country 1's fixed costs associated with the network are $F_1 = 1/3$. Equivalently for the case of indirect links between 1 and 2 we have $F_1 = 1/4$, since country 3 in the middle is burdened by the additional share $F_3 = 1/2$.

For the remainder of this paper, countries are symmetrically spaced: $ij = ji$ therefore $c_{ij} = c_{ji} = c, t_{ij} = t_{ji} = t$.

2.2.2 Setup of the trade model

Symmetric countries produce goods using only labour. Country n has a population L_n and two sectors. One sector is responsible for the production of a single homogeneous good that can be traded freely. This good is the numeraire. The other sector produces a continuum of differentiated varieties of a good that can be traded at a cost. Each specific variety is produced by a single monopolist. In both sectors firms can freely enter or exit production. The population works in the sectors, moves freely across sectors but not across countries and consumes goods. Each consumer is endowed with one unit of labour.

Demand — A representative consumer receives utility U from consuming q_0 units of the numeraire and q units of the differentiated variety ω which may be produced domestically or may be imported. Her preferences are given by a C.E.S. utility function over the continuum of differentiated varieties ω:

$$U = q_0^{1-\mu} \left[\int_{\omega \in \Omega} q_{ij}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}\mu}$$

where $\sigma > 1$ is the elasticity of substitution between pairs of varieties and Ω is the mass of available goods. Maximising utility subject to exhausting her labour income share, the representative consumer in country j has demand for differentiated goods:

$$q_{ij} = \frac{\mu L_j p_{ij}^{-\sigma}}{\sum_{j,i=1}^{N} \int_{\Omega} p_{ij}^{1-\sigma}(\omega) d\omega}$$

where the denominator represents an aggregate price if the set of differentiated goods was consumed as an aggregate good.

Production and Trade Costs — Good 0 is the numeraire homogeneous good. One unit of labour produces w and the price of the numeraire is normalised to 1, so that the wage is equal to the price of the good. In this respect the wage is set equal to 1 across countries due to free trade, and across the two sectors within each country.

One firm can produce one variety of the differentiated good. Labour costs for differentiated goods are split between a marginal and a fixed cost and thus the sector is characterised by increasing returns. The marginal cost consists of a constant parameter $\gamma > 0$ representing aggregate productivity and a variable trade cost. The variable trade cost is the net benefit term that stems from forming a link to another country. For domestic consumption the net benefit becomes by construction equal to the value of unity.

To produce and sell a variety ω either domestically or abroad, the firm in country i employs Labour input:

$$L(q) = \gamma \frac{q_{ij}}{v_{ij}} + F_i = \gamma \frac{q_{ij}}{\delta^{t_{ij}} - c_{ij|ij \in G}} + F_i$$

As such, if a direct link ij is formed the firm receives a benefit δ in the sense that $\frac{\partial \Pi}{\partial \delta} > 0$. In addition it incurs a transport cost c as $\frac{\partial \Pi}{\partial c} < 0$. In case of an indirect link, the firm receives a decayed benefit $\delta^{t_{ij}}, t_{ji} > 1$ and incurs no cost at all.

The firm solves its maximisation problem constrained by the quantity demanded. It sets its optimal price equal to a constant markup over the unit cost $p_{ij} = \frac{\sigma}{\sigma-1}\frac{\gamma}{v_{ij}}$. Positive profits incentivise firms to enter the sector exhausting the profit margin. At zero profits, each firm produces output $Q_i \equiv \sum_{i,j=1}^{k} q_{ij}/v_{ij} = \frac{F_i}{\gamma}(\sigma - 1)$.

Over all varieties ω produced in each country, the total labour input must equal the labour share in the increasing returns sector: $\int_{\omega \in \Omega} L_{q,i}(\omega) d\omega = \mu L_i$. Since each firm produces one variety, the number of firms becomes finite and equal to $n_i = \frac{\mu L_i}{\sigma F_i}$. Consequently the aggregate price index can be characterised as $\sum_{j,i=1}^{N} \int_{\Omega} p_{ij}^{1-\sigma}(\omega) d\omega = \sum_{j,i=1}^{N} n_i p_{ij}^{1-\sigma}$.

2.2.3 Equilibria and comparative static experiments

In this section equilibria for alternative network formations, symmetric geographical placement of countries, optimal prices given trade costs and traded quantities are characterised. The network-specific notions of stability and efficiency for each formation are defined and proved in Appendix A.1.

Two Country Equilibrium — The equilibrium is characterised by the zero profit condition across two countries due to free entry and exit of firms within each country. The net benefit term associated with the two countries becomes $v_{12} = \delta - c = v_{21}$ because of symmetry of the two direct links g_{12} and g_{21}. Then it must be that profits are $\pi_1 = \pi_2 = 0$. Given that fixed costs of production are equal and countries differ only in their size, the zero profit condition can be written compactly as:

$$\sum_{1,j=1}^{2} q_{1j}(p_{1j} - \frac{\gamma}{v_{1j}}) = \sum_{2,j=1}^{2} q_{2j}(p_{2j} - \frac{\gamma}{v_{2j}}) \Rightarrow Q_1 = Q_2$$

Domestic prices are equal across countries as γ is a common constant. Prices abroad differ only by the net benefit term which is symmetric. By expanding the price indices in country 1 and 2 given domestic prices and prices abroad, in equilibrium the home market effect is yielded:

$$\frac{n_1}{n_2} = \frac{\frac{L_1}{L_2} - (\delta - c)^{\sigma-1}}{1 - \frac{L_1}{L_2}(\delta - c)^{\sigma-1}} > 0$$

Introducing a network leaves things unchanged in the standard model of trade with two countries. Yet a notable remark is that the decision to export entails an additional inherent condition for the firm. Provided the cost of transport will never exceed the benefit and as long as profits cover the fixed costs, the firm will always be favourable towards establishing a link.

The link is beneficial for society as utility increased due to the greater number of varieties available to consumers. Clearly there is autarky when $c > \delta$ and the benefit is greater the more proximal countries 1 and 2 are. Thus in equilibrium if the relative size of country 1 increases there is a more than proportional increase in the relative number of domestic firms given the net benefit of forming a direct link. The condition holds as long as $(\delta - c)^{\sigma-1} < \frac{L_1}{L_2} < (\delta - c)^{1-\sigma}$ and n_1 and n_2 are non-zero.

Three Country Equilibrium — Similarly to Krugman (1993), the three country example entails a strong simplifying assumption that will enable construction of the equilibrium: That is all countries have the same size $L_1 = L_2 = L_3 \equiv L$ so that the number of firms is also equalised: $n_1 = n_2 = n_3 \equiv n$. Essentially the home market effect between any two trading partners in a three country world is normalised to 1.

The impact of the network structure becomes apparent when a firm has to consider whether it will form a direct link or an indirect link to a trading partner. In order to form an indirect link it must have implicitly formed a direct link with another partner. Exploiting the symmetry assumption any decision that a firm in country 1 may make is an equivalent decision for a firm in the complement countries. Therefore I focus on the decision of a firm in country 1 that has the option to trade directly with country 2 or indirectly with country 2 via country 3.

Similarly as in the two country case, the equilibrium with three countries is characterised by the zero profit condition $\pi_1 = \pi_2 = \pi_3 = 0$ irrespective of the types of links formed and written as:

$$\sum_{1,j=1}^{3} \frac{q_{1j}}{v_{1j}} = \sum_{2,j=1}^{3} \frac{q_{2j}}{v_{2j}} = \sum_{3,j=1}^{3} \frac{q_{3j}}{v_{3j}} \Rightarrow Q_1 = Q_2 = Q_3$$

While this expression may not be of particular interest, it is employed to infer selection from two available network formations. This will occur through the differences across the price indices when alternate formations occur. Consider first the case of a network consisting only of direct links.

Direct Links Network — The net benefit term becomes $v_{ij} = \delta - c$ for all pairs in the network. The zero profit condition and the assumption of no home market effect equalises production output across countries. The price index that any country faces is an aggregate measure of domestic prices and imported prices given the types of links established. For country 2 for example it can be expressed as:

$$P_2 = n\left(\frac{\sigma}{\sigma-1}\gamma\right)^{1-\sigma}\left(1+2(\delta-c)^{\sigma-1}\right)$$

Indirect Links Network — In the case of indirect links between countries 1 and 2 and direct links with country 3, the same equilibrium condition must hold, $Q_1 = Q_2 = Q_3$. The price index with one indirect connection and one direct is written:

$$P_2 = n\left(\frac{\sigma}{\sigma-1}\gamma\right)^{1-\sigma}\left(1+(\delta-c)^{\sigma-1}+(\delta^2)^{\sigma-1}\right)$$

where the term δ^2 indicates the benefit from having a hub location intervening between countries 1 and 2. The two equilibria will be identical by the zero profit condition and the assumption of no home market effect if there are unique values of benefit δ and cost c such that the two price indices are equalised across the two networks. This single point accommodates indifference between network formations; otherwise a specific network formation would prevail and the zero profit condition would be violated for one or both of the two network formations as will be shown below. Equalising the two price indices across formations, there is a unique pair of transport cost c and benefit δ that admits the equilibrium condition:

$$\delta - c = \delta^2$$

This unique cost level eliminates any benefit from choosing one particular formation such that the firm becomes indifferent between network formations.

It may also be the case that for a given value of benefit δ the values of transport costs admit an equilibrium where only direct or indirect links are formed. Consider a set of transport costs ranked in ascending order, $\mathbf{C} = \{\ldots, \bar{c}, \ldots, \hat{c}, \ldots\}$ and $c \in \mathbf{C}$. Suppose that a permanently high cost shock, c, is introduced between country 1 and 2. The two countries could continue trading directly. The profits for a firm in country 1 trading with 2 and 3 are (notation D denotes a direct links network):

$$\pi_1^D = q_{11}(p_{11}-\gamma) + q_{12}^D(p_{12}^D - \frac{\gamma}{\delta-c}) + q_{13}^D(p_{13}^D - \frac{\gamma}{\delta-c})$$

Whilst the profits for the same firm if it chose to trade indirectly with country 2 using country 3 as a hub (notation I denotes a network with one indirect link) become:

$$\pi_1^I = q_{11}(p_{11}-\gamma) + q_{12}^I(p_{12}^I - \frac{\gamma}{\delta^2}) + q_{13}^I(p_{13}^I - \frac{\gamma}{\delta-c})$$

The decision of the firm to change network formation arises by minimising losses given a constant benefit δ and a variable cost c. The indirect network formation will prevail if the cost from forming a direct link is very high. Then the firm may decide to sever the direct link and begin trading indirectly. In this way it has the option to remain in the market otherwise see its profits decrease and exit the market. Setting the equilibrium condition to $0 = \pi_1^I > \pi_1^D$ determines when the indirect links network formation prevail. Solving the inequality yields the simple relationship $\delta - c < \delta^2$. Then denote as $c = \bar{c}$ the infimum of high transport costs such that the inequality holds and the equilibrium condition is satisfied, $\bar{c} = \inf\{c \in \mathbf{C} : \delta - c < \delta^2\}$ and $0 = \pi_1^I(\bar{c})$: The equilibrium network will be the indirect network. Given a high transport cost $\bar{c}$ or above (as long as the cost is not high enough to induce autarky), it is more sensible for the firm to choose a hub network formation with the equilibrium holding only when $c = \bar{c}$. The hub formation thus minimises each country's exposure to transport costs.

Alternatively, when there is a permanently low transport cost $c < \bar{c}$, the direct network formation will prevail and a firm will suffer losses if it is trading indirectly. Setting the equilibrium condition to $0 = \pi_1^D > \pi_1^I$ determines when will the direct links network formation emerge. As expected, it gives the simple solution $\delta - c > \delta^2$ implying $c < \bar{c}$. The equilibrium $0 = \pi_1^D$ will be satisfied when $c = \delta$. When connectivity costs are low it becomes beneficial to form all direct links. The cost of adding a link is less than the benefit the firm gains from shortening the link of length two (δ^2) into a link of length one.

When the transport cost is extremely high, none of these formations should prevail and countries become autarkic. The autarkic equilibrium requires that firm profits are negative for both formations simultaneously. If costs are such that $c > \delta + \delta^2$ then indirect trading is prevented and because $c > \delta$ direct trading is prevented. For the equilibrium to be autarky for all partners, due to symmetry, it must be that simultaneously both of the above statements are true. This holds when c obtains the threshold value $\hat{c}$ or higher, where $\hat{c} = \inf\{c \in \mathbf{C} : c > \delta + \frac{\delta^2}{2}\}$.

These conditions coincide with Proposition 1 of Jackson & Wolinsky (1996). I summarise them as follows:

For unique values of c in the set $\boldsymbol{C}$ and holding constant the benefit term δ, the network formation decisions for a representative firm in the symmetric trade model with increasing returns are:

i. *A direct links formation when $0 \leq c < \bar{c}$ where the equilibrium holds if $\delta = c$.*

ii. *A hub formation when $\bar{c} \leq c < \hat{c}$ where the equilibrium holds if $c = \bar{c}$ for a given $\delta < c$.*

iii. *Autarky if $\hat{c} \leq c$ for a given $\delta < c$ and there exists a range of autarkic equilibria.*

iv. *Indifference between direct or hub formations if $\delta = \bar{c}$.*

v. *Indifference between autarky and a hub formation if $\bar{c} = \hat{c}$.*

vi. *Indifference between autarky and any network formation if $\delta = \bar{c} = \hat{c}$.*

These formations are *uniquely efficient* in the sense that each case is a prevailing case and no other network can accommodate higher profits. If costs are forbidding it does not make sense for a firm (or for a consumer at the receiving end) to proceed with trading (consuming) a specific variety. The empty network, or autarky is the only efficient outcome of the three country problem. If costs are high but less than the autarkic level for a given level of $\delta < c$, the only efficient network is the hub network. Autarky would have lower utility levels and direct links would give lower profits for the firm and lower consumption. For sufficiently low transport costs, the cost of adding an extra link is less than the firm's gain from replacing an indirect link to a direct link. And so it will always prefer to have a direct link at these costs. The same applies for the consumer.

The hub network is *stable* for cost values consistent with the range $\delta - \delta^2 \leq c$: country 3 being in the center, becomes worse off if a link is severed since utility for consumers there decreases. A firm in country 1 similarly is adversely affected by this choice. The indirect link is severed and the varieties traded decrease. Profits for the firm decrease. Therefore a firm will never choose to sever the link with country 3. Suppose also that a firm in country 1 forms a direct link at this cost level with country 2 instead of the indirect link via country 3. Profits from this configuration become less and thus the firm will never choose to do so. If it actually did, a firm in country 2 would have to sever another direct link with country 3 due to the high cost of maintenance. Thus the hub formation is *pairwise stable* but not necessarily unique as it can also rotate between countries. For lower transport costs all direct connections are pairwise stable as no country would be willing to sever a link. Therefore any two countries which are not directly connected benefit from forming a link.[1]

This approach develops a very simple economic concept. Contrary to the Krugman (1993) three country trade model, countries which are not necessarily benefited from concentration of production, possibly created by historical incidence, can yield hub network formations as well. This arises by incidence merely of geographical placement and as a form of hedging. In the Krugman model of trade with three countries, the equilibrium arises by postulating concentration of production and a defecting firm to survey other countries' production possibilities. Instead, herein one can simply postulate an excessively large transport cost and start to decrease it. At some autarkic liberating level, where for expositional clarity the benefit δ is such that there is no indifference between formations nor it is too low to admit autarky, the profit of a firm producing only domestic goods can be increased. This happens because there is a benefit from entering the export market. The firm decides to export, due to the positive profit margin. But it also decides the formation that minimises exposure to the exceedingly high costs it faces. The network formation will be a hub configuration with indirect links and the number of firms enter the market driving profits to zero at a unique level $c = \bar{c}$ for a given $\delta < c$. Each firm's labour input would need to be increased since $\frac{\partial L(q)}{\partial c} > 0$ and

[1] See also Jackson (2003) for the intuition behind the definitions of efficiency and stability.

subsequently the number of firms or varieties would need to be decreased compared to a case when $c < \bar{c}$ holding δ constant ($\frac{\partial n}{\partial L(q)} < 0$). If it happened to be that costs are lower, and specifically when $\delta = c$, each firm's labour input $L(q)$ would be decreased freeing up units of labour. Due to the full employment condition, the available labour input translates into an increase in the number of firms or traded varieties. More firms entering the sector decrease profits to zero at the unique level $\delta = c$, yielding an equilibrium where trading only occurs directly between countries.[2]

2.3 Empirical strategy and endogeneity

Stemming from the theoretical model, this section derives the empirically testable expression for aggregate trade in the manufacturing sector of a country with representative firms. However, in place of iceberg transport costs, the net benefit term embedding network structure is introduced. The presence of the net benefit term implies the existence of a trade off: a shorter distance to the destination dictates a lower cost and higher benefit whilst indirect trades are associated with evermore discounted benefits at no additional costs.

An empirical problem arises however as the benefit from forming a link is unmeasurable and does not reflect a realistic representation of a transport cost. In order to yield a testable prediction, the aforementioned trade off is modelled as an endogenous routing decision that is common for all firms across sectors as exports are observed at higher aggregation levels in the data. This decision can either be made by manufacturing firms themselves or a transport firm which posts the optimal shipping price that firms take as given. It will be expositorily easier to test the predictions of the model by employing the latter line of argument.

The decision for a firm to trade via a hub is the result of transport costs being sufficiently less to and from the hub versus the alternative decision to trade directly to the destination (Krugman 1993). The derivation of lower total transport costs depends on the form of the cost function of a transport firm which is assumed to incorporate the network structure and exhibits increasing returns to scale. If exports using a hub network prevail, fixed costs of transport are reduced because the network participation share for a trading partner is decreased. But distance, representing the marginal cost of transport, increases. This setting will be preferred against a network formation with direct links holding constant export volumes. Otherwise the opposite should hold: For direct links distance is less but fixed costs are higher and the overall costs for transporting the same export volume would be lower. I claim and prove in Appendix A.2

[2]See also Krugman (1979) for similar comparative static experiments.

that such a trade off is an outcome of increasing returns to scale in the transport sector. This alternative setting confirms qualitatively, yet in a more cumbersome way, the parsimonious theoretical exposition presented in the previous section.

For a particular sector, the equilibrium expression for the gravity equation is defined as the value of exports from i to j of all firms belonging in this sector. It is equivalent to $x_{ij} = n_i p_{ij} q_{ij}$ or,

$$x_{ij} = L_i \mu_j L_j \frac{v_{ij}^{\sigma-1}}{\theta_j} \frac{1}{\sigma F_i}, \text{ where } \theta_j = \sum_{j,l=1}^{N} n_l v_{lj}^{\sigma-1} \tag{2.2}$$

and θ_j is an aggregate index of network costs in j, derived from the price index. F_i represents country i's network participation share which I assume to be positively correlated with fixed costs. Since it is not possible to measure the net benefit from forming a link, I decompose the problem into two parts. First, the transport cost proxy is replaced with the distance between i and j assuming that transport costs are of the form $c_{ij} = d_{ij}^{\beta} \times exp(\beta_0)$ (see for example Hummels, Lugovskyy & Skiba (2009)). Second, for every network formation there are fixed costs correlated with the network structure and burden all firms uniformly in a specific country.

Hence the gravity equation of exports between two countries involving also a hub will incorporate an increase in distance. It will also involve a reduction in fixed costs by lowering country $i's$ network participation share which acts as a benefit of forming this particular indirect link. But if there is no hub involved, the gravity equation is just the standard outcome of the trade model with representative firms and fixed costs are proportional to forming and maintaining direct links to all partners.

Suppose that the hub country/region is k. Country i trades with j via k. Denote x_{ij}^I as the aggregate exports using indirect links, or the hub k. If k is not involved, aggregate exports using direct links are denoted x_{ij}^D . Writing equation (2.2) in logarithmic form, sectoral export volumes for direct and indirect trading become respectively:

$$\ln x_{ij}^D = \beta_0 + \beta_1 \ln L_i + \beta_2 \ln(\mu L_j) - \beta_3(\sigma - 1) \ln d_{ij} - \beta_4 \ln F_i^D - \ln(\sigma\theta_j) \tag{2.3}$$

and,

$$\ln x_{ij}^I = \beta_0 + \beta_1 \ln L_i + \beta_2 \ln(\mu L_j) - \tilde{\beta}_3(\sigma - 1) \ln(d_{ik} + d_{kj}) - \tilde{\beta}_4 \ln F_i^I - \ln(\sigma\theta_j) \tag{2.4}$$

We can control for country size and the impact of relative prices, herein the aggregate network cost indices θ_j, by using country fixed effects as in Chaney (2005). This operation however will absorb the variation of country specific fixed costs crucially rendering β_4 and $\tilde{\beta}_4$ useless in explaining any cost saving benefits of trading via the hub. Yet under such a specification we can conduct consistent and efficient estimation of the partial effects of the remainder regressors (Greene 2008). Interacting the distance variable in

(2.4) with a binary variable indicating the presence of a hub, provides an alternative way of observing impacts stemming from the presence of hubs in a route. If there is a hub involved between two countries trading, it must imply that transport costs were very high thus preventing direct connections with the opposite holding true holding export volumes constant. Equations (2.3) and (2.4) thus obtain their testable form as follows:

$$\ln \left[x_{ij}^s\right]^D = A_{ij}^{\prime s} + X_{ij}^{\prime} B_1 - \beta_3(\sigma - 1)\ln d_{ij} + \epsilon_{ij}^s \tag{2.5}$$

$$\ln \left[x_{ij}^s\right]^I = A_{ij}^{\prime s} + X_{ij}^{\prime} \tilde{B}_1 - \ln(d_{ik} + d_{kj})\left(\tilde{\beta}_3(\sigma - 1) + \tilde{\gamma}\text{Hub}_{ij}\right) + \xi_{ij}^s \tag{2.6}$$

Where prime denotes transpose, A_{ij}^s is a vector comprising a constant, a set of country and sector dummies, X_{ij} is a vector of trade barriers between countries i and j other than distance and ϵ_{ij}^s, ξ_{ij}^s are both orthogonal to the independent variables and normally distributed. I assume that the shocks affect trade flows within each country pair and so all observations are clustered at this level.

Clearly the two testable equations are not comparable as the level of export volumes that depend on the routing decision are different. But as the sectoral export volumes to a destination that are observed in the data are the maximum of the two equations, $\ln x_{ij}^s = \max\{\ln \left[x_{ij}^s\right]^I, \ln \left[x_{ij}^s\right]^D\}$, a comparison across equations is enabled by employing the common dependent variable. This crucially allows for testing whether the two partial effects of distance are significantly different from each other.

While it is not immediately apparent how the coefficient of indirect distance should behave relative to the direct distance counterpart, we anticipate the interaction to have a consistent ameliorating effect on the negative impact of the former variable. The aim therefore is to test whether the overall marginal effect of trading via a hub becomes significantly less in absolute value than the marginal effect of trading directly reflecting a discount in the cost of transport due to the interaction. With this strategy in mind, the dataset is introduced followed by a discussion on the expected magnitudes of the consistent estimators of β_3 and $\tilde{\beta}_3$.

2.4 Construction of the dataset

The dataset is constructed by merging data from various available sources. Exports from 2003 to 2007 are obtained through the World Bank WITS interface and the classification levels are 1, 2 and 6 digit HS 1988/1992 for all possible trading partners. These observations are matched with corresponding data on ad-valorem maritime transport costs of the same classification level and year. Observations for maritime transport costs as well as the mode of transport are available under subscription to the OECD Maritime Transport Costs Database.[3] The justification for selecting maritime transport costs is

[3]HS1 aggregated values are own constructs.

twofold. First, 99% of the world's trade by weight (Hummels 2007), and 90% of the volume of world trade is transported by sea (OECD 2008). Second, with the existence of hub and spoke networks induced by the advent of containerisation it is not strict to assume that the observed price of shipping services, i.e. transport costs, is a function of the network organisation of the transport sector.[4] By conducting this operation some of the global export volume that has been transported by sea and therefore by some form of network can be captured.

All observations not having matching exports and transport costs are removed. Each surviving trade partnership is assigned nominal GDP values, two measures of distance, border and language characteristics. GDP values are obtained through the World Bank Databank. Information on capital distances, contiguity and common language come from the CEPII GeoDist dataset compiled by Mayer & Zignago (2011).

In addition to capital distance, I construct a measure of indirect distance. For a subset of trading partners I measure the distance from the capital of the exporter to the closest major exporting port. The exporting port is located within the country of export and for the cases of landlocked countries the closest major foreign port is chosen, through which it may proceed to export. Then trading partner port distances are measured using the US National Imagery and Mapping Agency Distances Between Ports publication as well as the online resource Port World Distance Calculator. For each particular partnership, listed in Table A.12 of the Appendix, the main country ports of origin and destination are assessed using throughput volumes and the shortest shipping route is calculated. If the shipping route requires passage through any of the below exogenously imposed *hub* areas, the route is assigned an indicator value equal to one or otherwise zero. No such distinction is made for direct capital distance. These areas are the Panama Canal, the port of Gibraltar, Port Said, Singapore, Cape Town, Istanbul, Paranagua and the port of Arica. Finally the distance from the major importing port to the capital is measured. To provide an example of this construction, the direct capital distance between Beijing and Brasilia is 16,948 km. Indirectly, the distance from Beijing to Shanghai is 1,267 km, and from Shanghai to Singapore 3,934 km, where the indicator is assigned a value of 1. Then add the distance from Singapore to Rio (16,366 km) and Rio to Brasilia (1,160 km). The observation for indirect distance finally becomes 22,727 km.

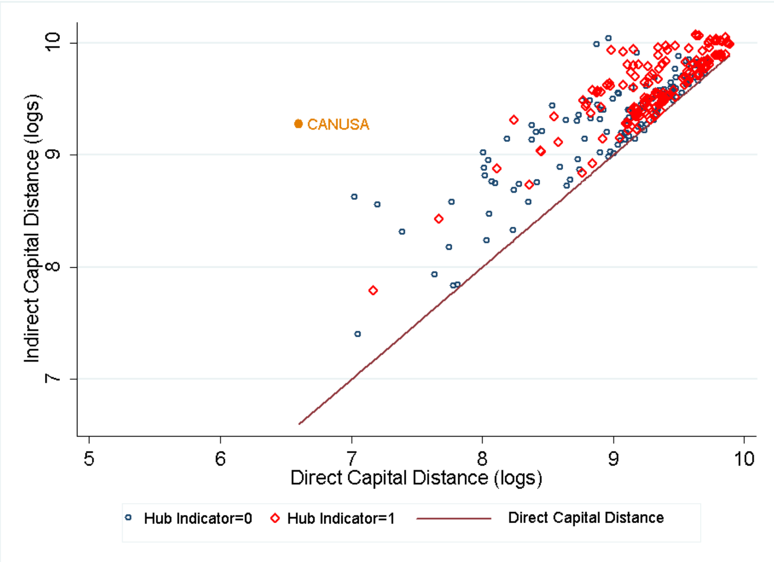
The data come with a weakness in the sense that transport costs for individual EU 15 countries are not observed. For this reason, and when otherwise not available, all other units are aggregated to provide approximations at the 15 country level. The capital distance of the EU 15 region with the rest of the world is then measured from Brussels and its main export/import port becomes Rotterdam. Estimations will be conducted with and without the presence of the EU 15 region and its biggest trading partner, the United States, in order to provide an additional level of robustness.

[4]For a treatise on the evolution of containerisation see Rua (2012).

Table 2.1: Direct and indirect flows

	Hub=0	Hub=1	Total
Flows	41,182	32,055	73,237
Flows(%)	*0.56*	*0.44*	*1*

Figure 2.1: Distribution of distances and hubs (2 digit level)



2.4.1 Description of the data and discussion

At the 2 digit aggregation level, 44% of the sampled trade flows involve passage through one of the above defined hub areas while for the complement the route does not involve a hub as shown in Table 2.1.

The distribution of direct and indirect distances is presented in Figure 2.1 where a systematic bias over longer distances is clearly observed. This will determine the expected magnitudes of the two distance coefficients. In addition, hubs appear to be positively correlated with distance.

An accounting exercise for obtaining the distribution of trade flows that utilise one or more hub locations is undertaken in Table 2.2. At the 2 digit level, 15,425 flows or 48% of the total flows that use a hub reach the destination after passing through one hub area. The remainder 16,630 flows use an additional hub after which 68% reaches the destination. Finally the residual 32% reaches the destination after using a third hub.[5]

[5]The following example presents a typical flow: For exports of 'Edible vegetables...' from India to Peru, goods leave the capital and are directed to Mumbai. The shortest shipping route requires passage through the Suez canal, Gibraltar and the Panama canal, until it reaches the port of Callao. Then the distance between Callao and Lima is added where it is assumed that the capital is the final destination. Because of the presence of the Suez Canal, Gibraltar and the Panama Canal an indicator variable is assigned the value of 1. If these areas were not present in the sea leg of the journey, then the indicator would take the value of zero.

Table 2.2: Number of hubs required for flows to reach the destination (2 digit level)

		Hub Location								
		CHL	EGY	EU 15	PAN	SGP	TUR	ZAF	Pass-through	Reach destination
1st Hub	Flows	257	5,663	13,289	3,280	7,112	670	1,784	32,055	15,425
	Flows (/100)	*0.01*	*0.18*	*0.41*	*0.10*	*0.22*	*0.02*	*0.06*	*1*	*0.48*
2nd Hub	Flows	0	8,323	3,509	1,156	300	0	3,342	16,630	10,787
	Flows (/100)	*0*	*0.26*	*0.11*	*0.04*	*0.01*	*0*	*0.10*	*1*	*0.65*
3rd Hub	Flows	0	0	2,666	457	2,720	0	0	5,843	
	Flows (/100)	*0*	*0*	*0.08*	*0.01*	*0.08*	*0*	*0*	*1*	

Table 2.3: Ranking of hub areas by passage count, levels and percentages (2 digit level)

Hub Rankings		
EU 15 - Gibraltar	19,649	0.357
EGY - Port Said	14,171	0.258
SGP - Singapore	10,256	0.186
ZAF - Cape Town	5,128	0.093
PAN - Panama Canal	4,893	0.089
TUR - Istanbul	670	0.012
CHL - Arica	257	0.005
Total	55,024	1

Table 2.3 shows at the 2 digit level, the frequency of passage through a particular hub and is the sum of the elements in each column of Table 2.2.

Addressing the systemic bias observed in Figure 2.1 which was associated with longer trades as validated in Table 2.2, Figures 2.2 and 2.3 exhibit how the difference between two distance observations is unaffected by changes in indirect distance, but decreases in direct distance. The implication is that direct distance observations approach in magnitude their indirect distance counterparts only over larger distances in the sample. Thus by overlapping the two distributions of distance, it seems that the right tail of the distribution of direct distance approximates that of indirect distance and as a consequence, the variance of direct distance must be larger.

Such a finding leads to the conjecture that the coefficient of indirect distance could possibly be weakly larger in absolute value than the coefficient of direct distance and the difference between the coefficients of the two distance variables could be statistically significant. This fact is confirmed initially in Figure 2.4. Adding the marginal effect of the interaction of indirect distance with a hub allows to recover which route has less impact on the same export volumes. This is obtained by testing which marginal effect is lower in absolute value and whether this difference is statistically significant. Figure 2.4 concludes the section by preliminarily indicating that the interaction term induces the overall reduction of the indirect distance effect compared to that of direct distance.

Figure 2.2: Distance differential as function of indirect distance.

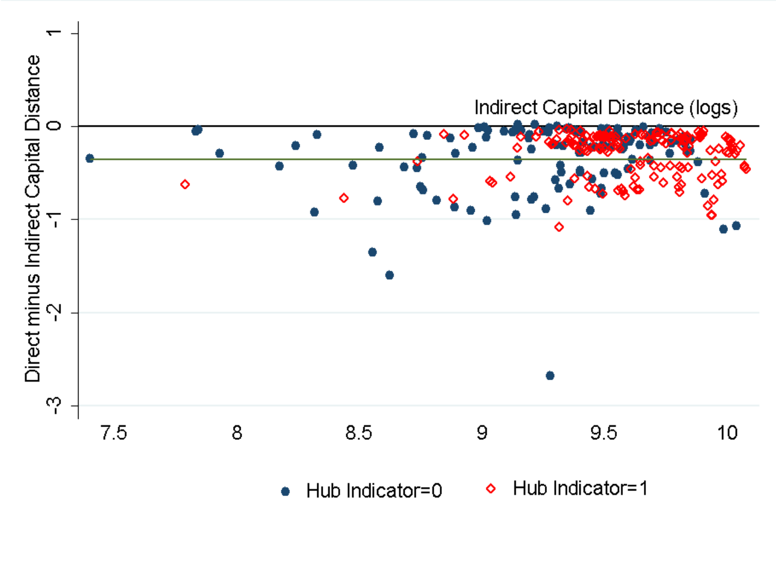
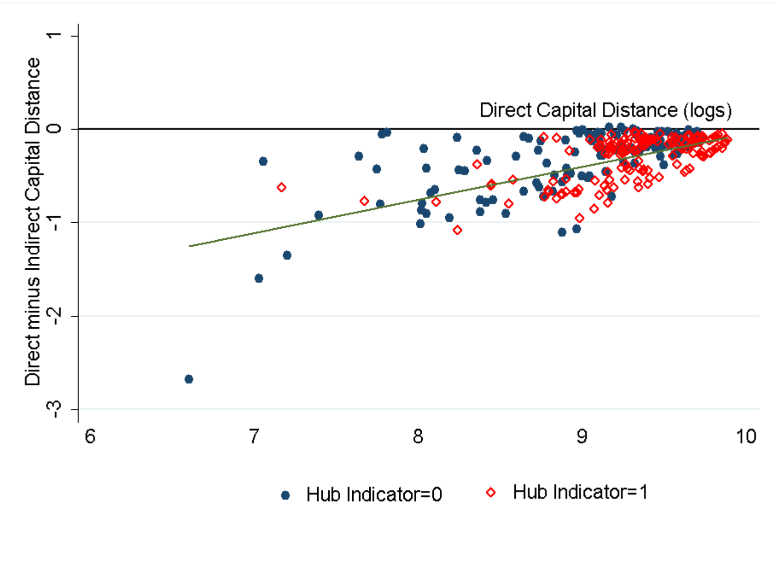


Figure 2.3: Distance differential as function of direct distance.



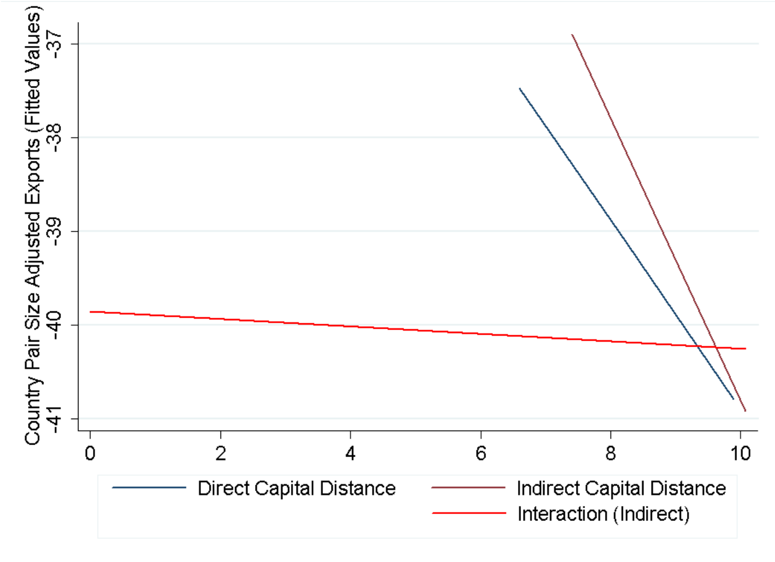
2.5 Estimation results

The analysis commences with a comparison between the distance coefficients $\hat{\beta}_3$ and $\hat{\hat{\beta}}_3$ at the total trade (1 digit), 2 digit and 6 digit levels and the outcomes of testing for their significant difference in magnitudes. It is achieved by estimating equation (2.5) alternately by including either the direct or indirect distance variables.

Table 2.4 lists the related coefficients for six different estimations depending on the level of robustness. Columns (1), (3) and (5) do not incorporate country and sector fixed effects while the complement columns do.[6] All estimations include however year fixed

[6]Note that at the 1 digit level no sector fixed effects are employed.

Figure 2.4: Fitted values of exports, marginal effects of distance variables and the interaction of hub indicator with indirect distance (2 digit level)



effects except for the 6 digit estimations, where only a cross section for 2006 is considered. Columns (1) and (2) exhibit outcomes following the estimation of coefficients in the raw sample after removing outliers. The results in columns (3) and (4) are characterised by increased robustness after having removed 2 studentised residuals. Columns (5) and (6) display results that were estimated, in addition to having 2 studentised residuals removed, after excluding the EU 15 and United States from the sample. The tables containing the full estimation results are relegated to Appendix A.3.

Across aggregation levels, it is found that the impact of the two distance variables on exports is indistinguishable as the p-values are greater than the 5% critical level. Confirming the intuition discussed in the previous section, it is also noted that the coefficients of indirect distance are weakly larger in absolute value yet this is not consistently observable. Lastly the coefficients for direct distance all fall within the range of surveyed estimates in the literature (Disdier & Head 2008, Overman, Redding & Venables 2001). While we cannot classify the indirect distance counterparts, their indistinguishable impact and their levels suggest that they do not diverge from the acceptable ranges.

Table 2.5 exhibits the outcomes of Equations (2.5) and (2.6). The respective robustness levels and inclusions of fixed effects that were outlined in Table 2.4 are preserved. The individual tables containing the regression results are listed in Appendix A.4. First I invoke a set of F-test results from the Appendix whereby the null hypothesis that the joint impact of the coefficient of indirect distance and the interaction is zero is rejected consistently across estimations and aggregation levels at the 1% and once at the 5% critical levels. Second, we observe that the coefficient of the interaction is not always statistically significant when not controlling for country and sectoral heterogeneity. Therefore inference cannot be deduced in these cases.

Table 2.4: Coefficients of direct distance versus coefficients of indirect distance, magnitudes and t-tests.

	(1)	(2)	(3)	(4)	(5)	(6)
			Total Trade			
$\hat{\beta}_3$ Direct Distance	-0.783***	-1.336***	-0.723***	-1.295***	-1.091***	-1.402***
$\hat{\hat{\beta}}_3$ Indirect Distance	-1.036***	-1.325***	-0.796***	-1.312***	-1.304***	-1.473***
$\hat{\beta}_3$ Direct Distance= $\hat{\hat{\beta}}_3$ Indirect Distance (p-values)	0.34	0.96	0.75	0.93	0.34	0.65
			HS2 level			
$\hat{\beta}_3$ Direct Distance	-0.822***	-1.34***	-0.856***	-1.291***	-0.973***	-1.481***
$\hat{\hat{\beta}}_3$ Indirect Distance	-0.965***	-1.537***	-0.991***	-1.502***	-1.144***	-1.520***
$\hat{\beta}_3$ Direct Distance= $\hat{\hat{\beta}}_3$ Indirect Distance (p-values)	0.42	0.24**	0.36	0.17	0.37	0.79
			HS6 level			
$\hat{\beta}_3$ Direct Distance	-0.432***	-0.897***	-0.439***	-0.863***	-0.592***	-0.816***
$\hat{\hat{\beta}}_3$ Indirect Distance	-0.514***	-0.866***	-0.505***	-0.847***	-0.659***	-0.759***
$\hat{\beta}_3$ Direct Distance= $\hat{\hat{\beta}}_3$ Indirect Distance (p-values)	0.53	0.86	0.58	0.92	0.65	0.59

Reported coefficients of direct distance and indirect distance. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample estimation with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample estimation with 2 studentised residuals removed after excluding the US and the EU 15.

Table 2.5: Coefficients of direct distance versus coefficients of indirect distance plus the interaction term and associated test outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
Total Trade						
$\hat{\beta}$ Direct Distance	-0.783***	-1.336***	-0.723***	-1.295***	-1.091***	-1.402***
$\left(\hat{\beta}\text{ Indirect Distance} + \hat{\beta}\text{Interaction}\right)$	-0.382*	-0.512**	-0.336	-0.668***	-0.601**	-1.012**
$\hat{\beta}$ Direct Distance= $\left(\hat{\beta}\text{Indirect Distance} + \hat{\beta}\text{Interaction}\right)$ (p-values)	0.35	0.01	0.30	0.03	0.21	0.14
HS2 level						
$\hat{\beta}$ Direct Distance	-0.822***	-1.34***	-0.856***	-1.291***	-0.973***	-1.481***
$\left(\hat{\beta}\text{ Indirect Distance} + \hat{\beta}\text{ Interaction}\right)$	-0.453*	-0.865***	-0.557*	-0.914***	-0.837	-1.136***
$\hat{\beta}$ Direct Distance= $\left(\hat{\beta}\text{Indirect Distance} + \hat{\beta}\text{Interaction}\right)$(p-values)	0.22	0.03	0.24	0.06	0.60	0.04
HS6 level						
$\hat{\beta}$ Direct Distance	-0.432***	-0.897***	-0.439***	-0.863***	-0.592***	-0.816***
$\left(\hat{\beta}\text{ Indirect Distance} + \hat{\beta}\text{ Interaction}\right)$	-0.67	-0.432**	-0.639	-0.492**	-0.381	-0.511***
$\hat{\beta}$ Direct Distance= $\left(\hat{\beta}\text{Indirect Distance} + \hat{\beta}\text{Interaction}\right)$(p-values)	0.22	0.05	0.27	0.06	0.30	0.01

Reported coefficients of direct distance and indirect distance plus interaction with the hub indicator. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area.

When incorporating country and sector fixed effects (the latter does not apply for the 1 digit level) however I find that the joint impact of indirect distance and its interaction with the hub indicator is significantly different and lower from the impact of direct distance. The hub indicator appears to be dampening the impact of indirect distance making it significantly less than the impact of direct distance in most experiments at the various aggregation levels. Specifically at the total trade level, trading via a hub has significant cost saving benefits relative to trading directly in two out of three specifications involving country dummies. While the last column shows that the benefit is not significantly different from trading without a hub, note that at this aggregation level once removing the two largest partners the sample size decreases substantially and therefore inference could be affected.

To illustrate the potency of these results consider the 2 digit level outcomes in column (4) of Tables 2.4 and 2.5. In the first instance it is found that a 1% increase in direct distance reduces export flows by about 1.3%. When trading indirectly (without assuming any presence of a hub) the impact on exports is magnified standing at 1.5%, however this difference is not statistically significant. It is understood also that the difference between magnitudes is the result of the variance of the direct distance variable being larger than that of indirect distance as discussed in the previous section. Including the interaction with a hub indicator, we now observe that the overall negative impact of indirect distance has reduced to 0.91% for every 1% increase. Compared to the impact of trading directly, it is deduced that trading by a hub can have ameliorating effects as there is a 0.38% saving in distance costs.

Generalising the outcome, at the 2 digit level in columns (2), (4) and (6) one observes that trading via a hub is beneficial for trading partners because relative to trading directly, there is a 0.39% increase in exports on average if an indirect route is selected, following a 1% reduction in distance. This difference is statistically significant at the 5% and 10% levels. At the 1 and 6 digit levels the average differential stands at 0.61% and 0.38% respectively showing a consistent positive impact of the hub indicator when interacted with distance.

The results further indicate that the performance and signs of the principal variables as shown in the Appendix, are those expected and in accordance to the empirical trade literature (see for example Limao & Venables (2001)). Yet the identification of the sign and magnitude of the hub indicator when interacted with distance is unresolved. A possible explanation for this outcome is that the hub indicator is correlated positively with distance and by extrapolation negatively correlated with size adjusted exports. Yet the negative correlation weakens over larger distances and turns positive possibly capturing the high volume of trade between the East Asian countries with the Western world. These trades occur exclusively via a hub such as Singapore or the Suez Canal. Therefore it is deduced that the interaction seems to be picking up the variation associated with longer trades and higher volumes while this cannot be identified using the traditional distance estimates.

The section concludes by confirming the existence of ameliorating benefits arising from trading via a hub location. Whilst the reasoning for utilising a hub lies not in the explanatory power provided by the hub indicator variable itself, this acts only as a proxy capturing lower bilateral network costs, we are able to recover a positive impact on trade flows. The hub indicator variable employed in the analysis so far was assumed to be uncorrelated with the error term and serves to reduce the omitted variable bias by acting as an element of the vector of trade barriers. Yet because it is a proxy for endogenous route selection one cannot rule out correlation with the independent variable. This issue is addressed by performing a manual two stage least squares estimation based on Chapter 18 of Wooldridge (2002) and the note by the same author available at the address contained in the footnote.[7]

The first stage entails performing a reduced form probit regression for the hub binary variable using indirect distance, the vector of trade barriers X_{ij}, and the absolute value of the time difference between origin and destination acting as exogenous variables. Obtaining the predicted probabilities I form an instrument that is the interaction of the predicted probabilities with indirect distance. In the second stage I perform an instrumental variables regression by instrumenting the endogenous interaction term with the constructed instrument. While the results could be produced for the 1 and 2 digit levels, software limitations due to the large number of fixed effects did not allow the estimation at the 6 digit level. The outcomes of the second stage together with the respective p-values of the Hausman test are contained in Appendix A.5.

The results are summarised in Table 2.6. The null of exogeneity is rejected in 11 out of 12 experiments at the 5% critical level and the impact of indirect distance with its interaction is always significantly less in absolute value compared to that of direct distance. Noting that the results, however encouraging, indicate also overall impacts that are positive, it is deduced that I cannot rule out mispecification of the first or second stage of the estimation process that I can attribute to the lack of a functional form for a binary hub indicator. In addition, this process cannot be generalised as the hub indicator acted as a proxy for reductions in network costs by positing the trade off between increases in marginal costs of transport versus reductions in fixed costs that are correlated with the country's location in the network. This identification problem and derivation of a functional form for establishing when a particular location becomes a hub are left for future work.

[7]http://www.stata.com/statalist/archive/2011-03/msg00188.html

Table 2.6: Coefficients of direct distance versus coefficients of indirect distance plus the instrumented interaction term and associated test outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
			Total Trade			
$\hat{\beta}$ Direct Distance	-0.783***	-1.336***	-0.723***	-1.295***	-1.091***	-1.402***
$\left(\hat{\beta}\text{ Indirect Distance} + \hat{\beta}\text{Interaction}\right)$	0.339***	-0.233***	0.664***	-0.421***	-0.236***	-0.938***
$\hat{\beta}$ Direct Distance= $\left(\hat{\beta}\text{Indirect Distance} + \hat{\beta}\text{Interaction}\right)$ (p-values)	0	0	0	0	0	0
			HS2 level			
$\hat{\beta}$ Direct Distance	-0.822***	-1.34***	-0.856***	-1.291***	-0.973***	-1.481***
$\left(\hat{\beta}\text{ Indirect Distance} + \hat{\beta}\text{ Interaction}\right)$	0.174***	-0.516***	0.052***	-0.593***	-0.717***	-1.052***
$\hat{\beta}$ Direct Distance= $\left(\hat{\beta}\text{Indirect Distance} + \hat{\beta}\text{Interaction}\right)$(p-values)	0	0	0	0	0	0

Reported coefficients of direct distance and indirect distance plus the instrumented interaction with the hub indicator. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area.

2.6 Conclusion

I study the reasons for formation and the impacts of transport hub networks in international trade by merging the symmetric connections model of Jackson & Wolinsky (1996) in a trade model of monopolistic competition with representative firms. Under the assumption of symmetric geographical placement of countries, respective domestic firms commence exporting and choose the trading network formation that is minimising their exposure to transport costs. When transport costs are extremely high countries remain closed. Upon their gradual reduction, firms commence exporting and create hub networks that are associated with higher levels of costs and then direct connections. The equilibrium is attained given a fixed benefit value for which a unique transport cost leads to satisfaction of the zero profit condition.

Empirically the existence of hub formations in maritime transportation –responsible for carrying the vast majority of traded goods– is confirmed, as firms in a sector choose the formation that maximises the volume of output to the destination. This is observed after interacting the distance of a trade route between capitals with a binary variable that indicates whether the route passes through a hub and comparing the overall marginal effect to that arising by using great circle capital distances: I document a 0.39% increase in exports on average if a route passing through a hub is selected relative to a direct route, following a 1% reduction in distance. Trading via a hub is found to be preferable over longer distances where the interaction term ameliorates the impact of the distance barrier. The results are also confirmed when the endogeneity of the indicator variable is accounted for.

Using an auxiliary model, hub formations are the outcome of economies of scale in transportation due to a trade off between increasing marginal and decreasing fixed costs. Transport costs on high-volume trading routes tend to be low (assuming that transport markups are not variable as in the case of Hummels, Lugovskyy & Skiba (2009)). This does not affect much the productivity or number of firms. Transport costs on low-volume trading routes are higher and distance here plays a crucial role. This should affect the productivity and number of exporting firms more severely. Additional factors could be directional imbalances penalising countries which cannot provide return cargoes, costs for importing and exporting commodities and exercise of market power (Hummels 2007).

I conclude that geographically disadvantaged countries absorbing high transport costs can achieve a more beneficial trading position by utilising a transportation hub. The link with at least one proximal geographically advantaged partner improves market access, ameliorates exposures to these costs and leads to improvements in own and transit infrastructure.

Avenues for future research in this area are the modelling of economies of density in transportation embedded in a trade model, deriving a functional form for the hub indicator and analysing the heterogeneity in fixed costs associated with infrastructure for which information is not presently available.

Chapter 3

Firm Heterogeneity and Asymmetric Trade with a Transport Sector - Implications of Trade Liberalisation

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We incorporate an international transport sector operating under increasing returns to scale into the standard Chaney-Melitz set-up model of firm heterogeneity, to understand the composition and contribution of the main drivers of observed growth in trade volumes (Baier & Bergstrand 2001, Yi 2003, Ruhl 2008). We show that tariff and transport cost reductions are complementary, and hence that the large estimates of price elasticities of import demand observed following liberating events can only be attributed in part to tariff reductions. By omitting trade policy induced adjustments in transport technology, the empirical researcher finds that tariff reductions appear too small to explain observed changes in trade growth.

Exploiting 2006 cross-sectional data from the OECD Maritime Transport Costs Database for 9 exporters and 36 importers at the HS6 level of disaggregation, we find that a 1 per cent increase in the quantity transported (*i*) reduces the ad-valorem shipping price by 4 per cent, conditional on distance and fob prices; (*ii*) increasing the probability to export by 4 per thousand percentage points, holding tariffs at their means, providing empirical support for the main mechanism. Finally, the normative implications are also novel: (*i*) the response of trade volumes to tariff cuts is amplified at both margins; (*ii*) the reallocation gains (and redistributional impact) identified in the literature on firm heterogeneity are magnified, and (*iii*) the extent and strength of such effects are related to the scope of the international transport network and mode of transport.

3.1 Introduction

Transport costs are comparable in size to tariffs, exhibiting large variation across products, jointly altering the patterns of and gains from trade (Hummels 2001, Hummels, Lugovskyy & Skiba 2009). Over the past fifty years, tariffs have decreased by about 11 per cent principally in manufactured goods (Yi 2003), raising the relative importance of transport costs as a trade barrier. Yet changes in transport costs over the same period are more complex to analyse. The remarkable technological advances that took place in ocean transport –responsible for carrying 99% of the world's trade by weight and 90% of the volume of world trade– in the form of containerisation, infrastructure development, minimisation of time spent loading and unloading at ports, have resulted in moderate if any shipping price reductions. These arise mainly through scale effects but have been overshadowed by inelastic transport supply, increases in input factors and market power (Hummels 2007, OECD 2008, Hummels, Lugovskyy & Skiba 2009, Stopford 2009).[1]

Hence the prominent explanations for the unprecedented growth in manufacturing export shares and become income growth and tariff reductions (Baier & Bergstrand 2001, Yi 2003). Indeed the latter is supported in empirical work by large values of the price elasticity of import demand, ranging from about 4 to 15, that account for growth in trade volumes from observed reductions in tariffs (Ruhl 2008).

Yet could there be a complementarity between tariffs and shipping prices? Is some of the variance in trade growth explained by shipping prices that have been affected by increased range and volume of transported goods as a result of trade liberating policies, all else constant? This paper puts forward that presence of scale economies in transportation may amplify the response of trade volumes to tariff declines but transportation may also dampen such responses by charging a shipping fee that is a function of the factory price of the good and a markup. The net effect is found to be positive, thus reconciling the theory with the aforementioned facts.

Consequently gains, losses and distributional impacts from trade liberalisation associated with i) an increased range of intra-industry traded goods, ii) productivity and efficiency gains/losses stemming from allocation of resources, iii) increases in scale and innovations for competing in larger markets (Winters 2004, Melitz & Trefler 2012, Melitz & Redding 2012) are magnified in the theoretical exposition of this study.

[1]Bernhofen, El-Sahli & Kneller (2013) provide evidence on the quantitative importance of technological innovation in transportation for trade growth. The diffusion of containerisation led to a 700 and 281 per cent cumulative average treatment effect in North-North trade and non North-North trade respectively compared to the equivalent effects for (non-) GATT membership standing at 285 and 55 per cent and (non-) FTA membership 45 and -92 per cent respectively. Hummels et al. (2009) report that alignment with the minimum markups in containerised shipping would decrease the freight by 34.6 per cent for the United States and 45.4 per cent for Latin America, while Bernhofen, El-Sahli & Kneller (2013) do not control for market power in containerised shipping. Thus the statement of Hummels (2007) that "dramatic [shipping] price declines are not in evidence" pertains toward gains stemming from intermodal transportation as the aforementioned authors point.

Yet the open question remains as to the composition and the contribution of the principal components spurring trade growth in manufacturing, since it is inferred that transport technology, which is normally perceived as uninteresting in theoretical and empirical work,[2] proves to be, in fact, very interesting: The large estimates of the elasticity of substitution following trade liberalisation events, could then be attributed partly to the liberating event itself and partly to adjustments in transport technology. By omitting trade policy induced adjustments in transport technology, the empirical researcher finds that tariff reductions may appear too small to explain observed changes in trade growth.

This paper contributes by modelling transport technology in the Chaney (2008) model of trade, and by presenting quantitative evidence pertaining to the significance of the proposed equilibrium elasticity of aggregate exports with respect to trade costs. Transport firms operate under increasing returns to scale. Marginal costs of transport comprise distance to the destination and an estimable degree of influence of exported commodities' factory prices as in Hummels & Skiba (2004).

Transport firms myopically observe a sector's factory prices and quantities of goods, allocating equal freight rates for a range of traded commodities similar in their characteristics (Lugovskyy & Skiba 2010, 2011). In this context, a tariff reduction results in intensive and extensive margin[3] export increases as the standard model predicts, and the sector's aggregate factory price as a corollary goes up. The market value of the shipping price is lowered, per unit costs decrease and transportation is perceived to be less costly, yet this is dampened by the weight transport firms place on the price of the good when deriving their optimal shipping price, reflecting packaging/insurance costs. Lower shipping prices promote another round of margin export increases, magnifying the respective elasticities. Since tariffs and shipping prices co-move, their impacts appear to be always comparable. The relative importance of trade costs thus decreases over time but there is variation within the vector of trade costs due to the friction caused by the contribution of factory prices to the marginal cost of transport.

The empirical experiments herein provide support to such propositions. Four estimable equations assist in testing the null hypothesis that the equilibrium elasticity of aggregate exports with respect to trade costs is unimportant. The first, following Hummels & Skiba (2004), yields that the weight placed on the factory prices of goods by transport firms is significant, of the order of 0.7. The quantity transported has a negative impact on shipping prices indicating scale effects are prominent, but their beneficial impact is dampened by the weight placed on the factory prices of goods. The second, based on Helpman, Melitz & Rubinstein (2008) concludes that jointly tariffs and shipping prices affect the extensive margin. The third step is reminiscent of Crozet & Koenig (2010) as the equilibrium elasticity of exports with respect to trade costs is calculated for each

[2]See for example ***Transportation Costs and Adjustments to Trade*** by David Hummels who expresses scepticism on the functional form of the iceberg cost and the use of proxies for transport costs such as distance.

[3]Defined as the level of exports of incumbent and new exporters respectively.

disaggregated sector. The distributions of elasticities exhibit negative first and third moments. Fourthly, using the methodology in Chaney (2005), the null hypothesis that the trade cost specific elasticities do not interact with variable trade costs is partly rejected.

Inference is made regarding three general points: Transportation technology adjustments do indeed play a role in shaping trade flows as not only distance but factory prices of goods and the quantity transported affect shipping prices, necessitating a structural form for shipping prices (Lugovskyy & Skiba 2011). Second, tariff reductions and shipping prices jointly affect the range of traded goods. A decrease in tariffs within a sector in the past, unequivocally raises the quantity transported in subsequent periods, altering shipping prices through the feedback relationship. The probability to export increases, affecting aggregate prices of traded goods, the quantity transported and so on. Third, the procedure implies that the high coefficients following trade liberating events could be observed because transport costs remain un-modelled yielding an issue of identification and specification.

As part of the trade costs' literature, this simple, albeit restrictive, model adds to the plethora of important outcomes that re-evaluate the seemingly innocuous iceberg cost assumption in international trade. The monicker *iceberg costs* can be defined as the finite set of variable trade barriers between two countries each entering independently, with its own elasticity and loglinearly (Feenstra 2004, Anderson & van Wincoop 2004). The element of the set associated with transport costs is represented by some measure of distance to the destination (Disdier & Head 2008).

Hummels (2007), Hummels, Lugovskyy & Skiba (2009), Lugovskyy & Skiba (2011), Clark, Dollar & Micco (2004) argue successfully that transport costs are not all about distance to the destination. Transportation is an industry itself characterised by increasing returns, fixed costs correlated with infrastructure and variable costs that depend on distance, productivity and the physical characteristics of transported goods. Scale effects are not only made possible by virtue of ship size, with larger ships deployed on voluminous routes and vice versa, but also arise in shipbuilding and port infrastructure along with a wealth of other interactions.[4]

Concomitantly not all trade costs can be classified as iceberg costs. Irarrazabal, Moxnes & Opromolla (2014) find that the additive element of trade costs is quantitatively important: Relative to the median price of a commodity times the iceberg cost, the additive

[4]Kalouptsidi (2011) finds investment volatility and shipping market entry is increasing as shipbuilding times decrease and fleets tend to be larger in absence of any shipbuilding time. Rua (2012) extends the Melitz (2003) model of trade to include transport technologies: she explains that containerized trade is diffused slowly and linearly, depending on fixed costs correlated with transport infrastructure, the spread speed of container leasing, network size, usage, income and neighbour effects. Adoption of container port infrastructure followed an S-shaped curve over the last half century determined by institutional barriers, country size and future expectations of containerised flows. Krautheim (2012) shows that informational spillovers lead to fixed costs reductions amplifying the effect of variable trade costs on trade flows.

component is on average 14 per cent which is unaccounted for in pure iceberg cost empirical frameworks. Additive transport costs are positively correlated with factory prices causing the trade share of high quality goods to increase: The confirmation of the Alchian and Allen hypothesis[5] by Hummels & Skiba (2004) provides further proof on the omission of information that the iceberg formulation can entail. Since demand for transportation is a derived demand, Hummels, Lugovskyy & Skiba (2009) show that additive transport costs and subsequent price correlation leads to increases in the markup of transport firms.

The remainder of this paper is structured as follows. Section 3.2 presents the economic environment in which manufacturing and transport firms exist. In section 3.3 the equilibrium conditions are outlined followed by a discussion regarding the qualitative properties of the model and comparative static experiments. Sections 3.4, 3.5, 3.6 are concerned with the empirical application for testing the predictions of the model. The last section concludes.

3.2 Theoretical Framework

There are N countries in a global economy. Country n produces goods using labour $\hat{L}_n$ sourced from the population L_n. Identical agents in n consume $H + 1$ goods produced domestically or abroad by H sectors and sector 0. Each sector $h \in H$ of country n is identified by the output of a single good h and consists of a mass of firms. Each firm produces a single variety of the h good which is indexed by the firm's unique productivity level ϕ. Sector 0 produces a homogeneous good labelled 0 and acts as the numeraire. Each country n has a transport sector T comprising firms that produce differentiated transport modes and have identical productivity. These modes ship quantities of the h good from country n to another country by pooling together domestically produced varieties. T operates using labour $\hat{L}_n^T$, thus $\hat{L}_n + \hat{L}_n^T = L_n$.

- ***Preferences***

A consumer, endowed with one unit of labour, working in the $h \in H$, 0 or T sectors, is characterised by constant elasticity of substitution preferences. She exhausts all her income on consuming q_0 units of the numeraire and $q_h(\phi)$ units of variety ϕ produced in sector h. Her preferences are defined over the set of all available varieties of a sector, Φ_h, receiving utility U:

[5]The Alchian and Allen hypothesis states that any external costs increase the relative consumption of the higher valued commodity if these costs are additive to the good's final price. If value is correlated with quality (as Hummels & Skiba (2004) show) then the Alchian Allen effect leads to increased trade of the relatively higher quality commodities.

$$U \equiv q_0^{\mu_0} \prod_{h=1}^{H} \left[\int_{\phi \in \Phi_h} q_h(\phi)^{\frac{\sigma_h - 1}{\sigma_h}} d\phi \right]^{\frac{\sigma_h}{\sigma_h - 1}\mu_h}, \text{ with } \mu_0 + \sum_{h=1}^{H} \mu_h = 1,$$

Where $\sigma_h > 1$ is the elasticity of substitution between any two varieties of a sector h.

- ***Production in sector 0***

Good 0 is traded at no cost and produced under constant returns. One unit of labour produces w_n and the good's price is normalised to 1, so that the wage is equal to the price of the good. In this respect the wage is set equal to 1 across countries and across H sectors within each country n. As H and 0 are segmented from the T sector, a strong assumption is that workers in T are rewarded exogenously the normalised wage so that the incentive to relocate to another sector of the domestic economy does not arise.

- ***Trade Barriers***

Each variety h is subject to costly trade. For one unit of a variety to be transported from country i to country j, a fraction τ_{ij} is used up such that $1/\tau_{ij}$ units of variety ϕ arrive.

This iceberg cost comprises of two types of trade barriers: $b_{ij} > 1$ encompasses all elements of a finite set of trade barriers that exist between i and j except for the element associated with transportation. f_{ij} is the iceberg shipping price paid to a transport firm of country n's transport sector T in order to transport y units of variety ϕ from i to j.

The shipping price takes a functional form adapted from Lugovskyy & Skiba (2010) and Lugovskyy & Skiba (2011). We will assume that it is calculated in monetary terms (at the market price of the good shipped) and is the same across varieties of a sector, denoted as $\hat{f}_h$. For example, producers of tennis shoes or basketball shoes pay the freight in units of those goods, $f_{ij}(\phi)$, yet the dollar value of the shipping price is the same across shoe types, $\hat{f}_{ijh}$.

We will also assume that shipping prices are likely to be positively correlated with the factory prices of varieties based on the compelling supporting evidence provided by Hummels & Skiba (2004), Hummels, Lugovskyy & Skiba (2009), Lugovskyy & Skiba (2011) and Irarrazabal, Moxnes & Opromolla (2014). Since the market value of the shipping price is the same across all varieties of the sector, it is natural to set a dependence between the shipping price and the average price of a sector's varieties – the aggregate factory price of the h good –.

This implies a myopic observation by the transport firm of a variety's actual factory price and the variety itself. The price aggregation and pooling of varieties is derived from commercial practice. First, it is inspired by the practice of a transport firm that receives a sealed consignment of goods to be shipped along with a *pro forma* invoice stating the fob price of the good and the declaration of goods. The transport firm's appointed individual then proceeds to complete the bill of lading using a STC (said to contain) and/or a STW (said to weigh) condition so that its liability is limited only to the number and/or weight of items but not the contents (the actual variety itself).

Second, modes of transport such as containerised transportation are able to ship a multitude of goods produced by firms within (tennis shoes, basketball shoes, etc.) and across sectors (refrigerated milk, shoes) by virtue of homogeneous cargo space (Stopford 2009, Levinson 2008).

The shipping price observed by firms producing the differentiated varieties of good h is:

$$(f_{ij} - 1) \left(E\{p_{iih}(\phi)\}\right) = \hat{f}_{ijh}$$

Where f_{ij} is the iceberg reward to transport firms and $\hat{f}_{ijh}$ is the market value of the shipping price. $E\{p_{iih}(\phi)\}$ is the average factory price of varieties in sector h or the aggregate price of good h. Solving for f_{ijh} yields:

$$f_{ijh} = \hat{f}_{ijh} \left(E\{p_{iih}(\phi)\}\right)^{-1} + 1 \tag{3.1}$$

The transport sector is monopolistically competitive and the cost function of a representative firm is:

$$c_h^T(q) = y_h q_{ijh}(\phi) d_{ij} (E\{p_{iih}(\phi)\})^{\beta_h} + F^T$$

Where $0 < \beta_h < 1$ is a percentage influence of the log domestic average price of good h on the log shipping price of good h which will be tested empirically for its statistical significance, $d_{ij} > 1$ is the variable cost associated with distance to the destination, F^T is the fixed cost associated with transport infrastructure. y_h are the units of the good shipped by a single transport firm which will be derived in equilibrium. The sector is characterised by increasing returns to scale as the unit cost of shipping a good decreases when traded volumes increase (see for example Hummels & Skiba (2004)).

- ***Firm heterogeneity and production***

Firms producing differentiated varieties are governed by the same technology within and across countries. Within each country and sector, they only differ in their level of productivity ϕ measured in labour units which is allocated after a random draw from a Pareto distribution with shape parameter γ_h. Productivity is distributed within an interval $[1, +\infty)$ according to:

$$P(\tilde{\phi}_h < \phi) = G_h(\phi) = 1 - \phi^{-\gamma_h}, \quad \text{with density} \quad dG_h(\phi) = g_h(\phi)d\phi \equiv \gamma_h \phi^{-\gamma_h - 1} d\phi$$

The parameter $\gamma_h > \sigma_h - 1$, $\gamma_h > 2$, is an inverse measure of heterogeneity within a sector. The higher the value of γ_h the more output is characterised as being produced by small less productive firms and vice versa.

Varieties are produced after firms in country i pay a variable cost $1/\phi$ and a destination specific fixed cost F_{ij}^M that allows them to export to a destination other than country i. Taking into consideration the destination specific trade cost τ_{ij}, the cost function of a particular firm in sector h is defined as:

$$c_{ijh}^M(q) = \frac{\tau_{ijh}}{\phi} q + F_{ijh}^M$$

This implies self-selection as exporting firms will be amongst the most productive. This however is not attributed to exporting itself, but to the fact that such firms are able to cover export market entry costs (Bernard, Jensen, Redding & Schott 2012). Lastly, the total mass of exporting firms in country i is proportional to its size, L_i.

- ***Timing and Strategies***

Consumers play first and yield their demand for an imported variety taking the destination prices of firms as given. Transport firms follow by posting their shipping price schedules to destination j based on the observed quantity demanded and the expectation of a particular variety's factory price. Firms draw a unit of labour with productivity ϕ, set prices based on their productivity level and subsequently select the number of destinations to sell their output to. The equilibrium is characterised by:

- A set of exporting firms identified by productivity levels that enable them to cover the fixed cost in order to export.
- A set of quantities and prices for each variety ϕ of sector h in each destination such that the quantity demanded is equal to the quantity supplied at a unique destination price.

3.2.1 Demand for differentiated goods

A consumer solves her maximisation problem by yielding her demand for variety ϕ of good h:

$$q_{ijh}(\phi) = \mu_h L_j P_{jh}^{\sigma-1} p_{ijh}(\phi)^{-\sigma_h}$$

Where P_{jh} is the aggregate price of the good at the destination. Firms associated with a low productivity draw will not be able to cover the fixed costs of exporting, given the set of trade barriers and subsequently produce only domestically. We will not be monitoring such firms directly. If ϕ^* is the productivity of the threshold firm that breaks even for a given level of fixed costs F^M_{ijh} and variable trade costs τ_{ij}, then the price index is defined as:

$$P_{jh}{}^{\sigma_h - 1} = \left[\sum_{k=1}^{N} L_k \int_{\phi^*_{kj}}^{\infty} p_{kjh}(\phi)^{1-\sigma_h} dG_h(\phi) \right]^{-1}$$

3.2.2 The price setting behaviour of transport firms

Transport firms derive their profit maximising price in monetary terms subject to the quantity demanded at destination j. Shipping a sector specific amount y of the quantity demanded q costs to heterogeneous firms:

$$\hat{f}_{ijh} = \frac{\sigma_h}{\sigma_h - 1} d_{ij} \left(E\{p_{iih}(\phi)\} \right)^{\beta_h}$$

Since the markup $\frac{\sigma_h}{\sigma_h - 1}$ is constant and greater than unity, it must be that $\hat{f}_{ijh} > 1$. With slight abuse of notation, the *exogenous* $+1$ term in equation (3.1) which is imposed to ensure that $\frac{p_{ij}}{p_{ii}} = \tau_{ij} > 1$, can be absorbed so that the iceberg reward to transport firms f_h is equal to the real price of shipping good h:

$$f_{ijh} = \frac{\hat{f}_{ijh}}{E\{p_{iih}(\phi)\}} \equiv \frac{\sigma_h}{\sigma_h - 1} d_{ij} \left(E\{p_{iih}(\phi)\} \right)^{\beta_h - 1} > 1 \tag{3.2}$$

With $E\{p_{iih}(\phi)\} = \int_{\phi^*_{ijh}}^{\infty} p_{iih}(\phi) dG_h(\phi)$ being the average factory price of varieties in sector h, which will be defined by the number of firms that are more productive than the threshold firm with productivity ϕ^*. Additionally, the lower bound of β_h is set to $\frac{\gamma_h}{\gamma_h + 1}$.[6] Hence $\tau_{ijh} \equiv b_{ij} \times f_{ijh} > 1$.[7]

3.2.3 The price setting behaviour of heterogeneous firms

Firms in i are constrained by the quantity demanded at destination j which is a function of the trade barriers b and the shipping price f. After drawing productivity ϕ they set their price as a constant markup of price over the marginal cost:

$$p_{ijh}(\phi) = \frac{\sigma_h}{\sigma_h - 1} \frac{\tau_{ijh}}{\phi}$$

After obtaining the partial equilibrium results, one can now proceed to characterise the general equilibrium of this global economy.

[6]This ensures that a positive elasticity never materialises.

[7]Since there are no domestic trade costs the convention $\tau_{ii} = 1$ is adopted.

3.3 Equilibrium export participation and exports

3.3.1 Productivity threshold and the shipping price

Only the subset of the most productive firms are able to overcome the country j-specific fixed cost barrier. The productivity of the threshold firm of sector h[8] which is characterised by variable profits accrued from exporting to j that are exactly offsetting the fixed costs of export participation is:

$$\phi^*_{ij} = \left(F^M_{ij}\right)^{\frac{1}{\sigma-1}} \left(P_j L_j^{\frac{1}{\sigma-1}}\right)^{-1} b_{ij} d_{ij} \times \left(E\{\phi^{-1}\}\right)^{\beta-1} \lambda_1 \tag{3.3}$$

where λ_1 a constant.[9]

At the same time the productivity threshold ϕ^* becomes known, the price of shipping good h to country j is obtained:

$$f_{ij} = \left(\frac{\sigma}{\sigma-1}\right)^{\beta} d_{ij} \left(\phi^*_{ij}\right)^{-(\gamma+1)(\beta-1)} \left(\frac{\gamma}{\gamma+1}\right)^{\beta-1} \tag{3.4}$$

The shipping price has propagating effects on the productivity threshold since it is a function of ϕ^*_{ij} itself if $\frac{\gamma}{\gamma+1} < \beta < 1$.

3.3.2 Aggregate prices at the destination

By replacing the expected productivity level in the productivity threshold equation (3.3) the equilibrium price index is obtained. In the process the share of each country's relative size to the world $s_k = L_k/L, L = \sum_{k=1}^{N} L_k$ is defined, resulting in:

$$\begin{aligned} P_j &= \left(\frac{L_j}{L}\right)^{\frac{1+(\gamma+1)(\beta-1)}{\gamma}} (L_j)^{-\frac{1}{\sigma-1}} \theta_j \lambda_2 \\ \text{where } \theta_j^{-\gamma} &= \left(\sum_{k=1}^{N} s_k\right)^{1+(\gamma+1)(\beta-1)} (b_{kj} d_{kj})^{-\gamma} \left(F^M_{kj}\right)^{-\left(\frac{\gamma}{\sigma-1} - (1+(\gamma+1)(\beta-1))\right)} \end{aligned} \tag{3.5}$$

Where λ_2 is a constant[10] and θ_j represents an aggregate index of country j's remoteness from the rest of the world.

[8] Henceforth we drop the subscript h for simplicity.

[9] $\lambda_1 = \left(\frac{\sigma}{\mu}\right)^{\frac{1}{\sigma-1}} \left(\frac{\sigma}{\sigma-1}\right)^{1+\beta}$

[10] $\lambda_2 = \frac{\gamma-(\sigma-1)}{\gamma}^{\frac{1+(\gamma+1)(\beta-1)}{\gamma}} \left(\frac{\sigma}{\mu}\right)^{\frac{1}{\sigma-1} - \frac{1+(\gamma+1)(\beta-1)}{\gamma}} \left(\frac{\sigma}{\sigma-1}\right)^{(1+\beta)} \left(\frac{\gamma}{\gamma+1}\right)^{\beta-1}$

3.3.3 General equilibrium productivity threshold, exports and aggregate exports

Within a specific sector h of country i, there is a simultaneous solution for the equilibrium set of exporters, $\Phi_j^* \subseteq \Phi$ where $\Phi_j^* = \{\phi_{ij}^*, ..., \infty\}$, and for the export levels of each incumbent exporter provided their productivity exceeds the threshold:

$$\phi_{ij}^* = \left(F_{ij}^M\right)^{\frac{1}{(\sigma-1)(1+(\gamma+1)(\beta-1))}} \left(\frac{L_j}{L}\right)^{-\frac{1}{\gamma}} \left(\frac{b_{ij}d_{ij}}{\theta_j}\right)^{\frac{1}{1+(\gamma+1)(\beta-1)}} \lambda_3 \tag{3.6}$$

$$x_{ij}(\phi|\phi \geq \phi_{ij}^*) = \left(\frac{L_j}{L}\right)^{\frac{\sigma-1}{\gamma}} \phi^{\sigma-1} \left(\frac{b_{ij}d_{ij}}{\theta_j}\right)^{-\frac{\sigma-1}{1+(\gamma+1)(\beta-1)}} \left(F_{ij}^M\right)^{\frac{(\gamma+1)(\beta-1)}{1+(\gamma+1)(\beta-1)}} \lambda_4 \tag{3.7}$$

where λ_3 and λ_4 are constants.[11]

Aggregating over the level of exports of each incumbent firm will determine the level of sector h's total exports. Given that the number of firms is proportional to the country size L_i, total exports expressed in fob terms are:

$$X_{ij} = \int_{\phi_{ij}^*}^{\infty} L_i x_{ij}(\phi) dG(\phi) = \mu \frac{L_i L_j}{L} \left(\frac{b_{ij}d_{ij}}{\theta_j}\right)^{-\frac{\gamma}{1+(\gamma+1)(\beta-1)}} \left(F_{ij}^M\right)^{-\left(\frac{\gamma}{\sigma-1}\frac{1}{1+(\gamma+1)(\beta-1)}-1\right)} \tag{3.8}$$

3.3.4 Intensive and extensive margin elasticities

We now assess specifically the impact of the transport sector on the intensive (IME) and extensive (EME) margins of trade, whilst derivation of the elasticities of each margin are relegated to Appendix B.1.

The aggregate exports' elasticity with respect to variable trade costs b_{ij} can be decomposed to the intensive and extensive margin elasticities:

$$\begin{aligned} \epsilon_{b_{ij}} = -\frac{\partial X_{ij}}{\partial b_{ij}} \frac{b_{ij}}{X_{ij}} &= \left[IME_{b_{ij}} + EME_{b_{ij}}\right] \times \text{Shipping Price Effects} \\ &= [(\sigma-1) + \gamma - (\sigma-1)] \times \frac{1}{1+(\gamma+1)(\beta-1)} \\ &= \gamma \times \frac{1}{1+(\gamma+1)(\beta-1)} \end{aligned} \tag{3.9}$$

The elasticity of substitution σ has opposite effects on each margin as it magnifies the impact of variable trade costs on the intensive margin but decreases the impact of variable trade costs on the extensive margin. Since the elasticity of substitution affects both margins by the same rate but oppositely, it cancels out. The only determinant

[11] $\lambda_3 = \left(\frac{\sigma}{\mu}\frac{\gamma}{\gamma-(\sigma-1)}\right)^{\frac{1}{\gamma}}$ and $\lambda_4 = \mu\left(\frac{\sigma}{\mu}\right)^{1-\frac{\sigma-1}{\gamma}} \left(\frac{\gamma-(\sigma-1)}{\gamma}\right)^{\frac{\sigma-1}{\gamma}}$.

of the aggregate trade flow elasticity with respect to variable trade costs becomes the degree firm heterogeneity. In the presence of a good specific, price setting transport sector, both margins are amplified by the same elasticity $\frac{1}{1+(\gamma+1)(\beta-1)}$. As the term is greater than one, aggregate exports are more elastic relative to the Chaney (2008) model of trade[12] unless transport firms take into consideration wholly the factory price of the good.

Concerning the aggregate exports' elasticity with respect to fixed costs one obtains:

$$\begin{aligned}
\epsilon_{F_{ij}^M} = -\frac{\partial X_{ij}}{\partial F_{ij}^M}\frac{F_{ij}^M}{X_{ij}} &= \left[IME_{F_{ij}^M} + EME_{F_{ij}^M}\right] \times \text{Shipping Price Effects} \\
&= \left[-(\gamma+1)(\beta-1) + \frac{\gamma}{\sigma-1} - 1\right] \times \frac{1}{1+(\gamma+1)(\beta-1)} \\
&= \frac{\gamma}{\sigma-1} \times \frac{1}{1+(\gamma+1)(\beta-1)} - 1
\end{aligned} \tag{3.10}$$

The elasticity of substitution may have no impact on the intensive margin, but because of the presence of the transport sector, the intensive margin elasticity is positive: The more heterogeneous a sector is, given β, the less incumbent firms are harmed by a reduction in fixed costs. New participants to trade are more benefited from a reduction in fixed costs if the sector is more homogeneous with the opposite holding true. Lower values of σ decrease the extensive margin elasticity in a similar fashion to the Chaney (2008) model of trade.

3.3.5 Volume transported by each transporter and number of transporters

By assuming a representative firm framework in the transport sector, the number of transport firms is decreasing in fixed costs and the shipping capacity produced by a representative firm is increasing in fixed costs (Krugman 1979, 1980). Defining the parameter y as the ratio of total volume shipped to destination j to the total number of transport firms, $\frac{\int_{\phi_{ijh}^*}^{\infty} q_{ijh} dG_h(\phi)}{\sharp\text{firms}_{ijh}} \equiv y_{ijh}$, or the units of good h shipped by each firm, one can solve for the zero profit condition in the transport sector of country i:

$$y_{ijh} = \left[\frac{L_j}{L}\right]^{-\frac{(\sigma-1)}{\gamma}} \phi^{-\sigma} \left(\frac{d_{ij}}{\theta_j}\right)^{\frac{(\sigma-1)}{1+(\gamma+1)(\beta-1)}} F_{ij}^t \left(F_{ij}^M\right)^{-\frac{(\gamma+1)(\sigma-1)(\beta-1)}{(\sigma-1)(1+(\gamma+1)(\beta-1))}} b_{ij}^{\left(\frac{\sigma+(\gamma+1)(\beta-1)}{1+(\gamma+1)(\beta-1)}\right)} \lambda_5$$

Where λ_5 is a constant.[13]

[12] And always more elastic than the Krugman (1980) model of trade.

[13] $\lambda_6 = \frac{\gamma}{\gamma-(\sigma-1)}^{\frac{(\sigma-1)}{\gamma}} \left(\frac{\sigma}{\mu}\right)^{\frac{(\sigma-1)}{\gamma}} \left(\frac{\sigma}{\sigma-1}\right)^{-(\sigma-1)(\beta-1)}$

3.3.6 Discussion and comparison with the Chaney (2008) model of trade

Several remarks are in order. Transport firms are able to lower unit costs the higher the quantity shipped to the destination. Yet the dependence of the shipping price on the average factory price of the good, β, affects average shipping costs alleviating or reinforcing beneficial cost savings ensuing from economies of scale.

Ceteris paribus, a higher productivity threshold, leads to a higher iceberg reward to transport firms, as through equation (3.4), f_{ij} is increasing in ϕ^*_{ij}: Since factory prices decrease, the shipping price expressed as a percentage of the factory price of the good increases by a rate of $\gamma + 1$. Yet the marginal cost of shipping is a function of the factory price of the good itself. Hence a higher β, reduces the positive correlation between the productivity threshold; the real shipping price increase is attenuated: Marginal shipping costs decrease with respect to the productivity threshold ϕ^* at a rate $-(\gamma + 1)\beta$ and therefore the shipping price expressed as a percentage of the factory price of the good increases yet at a lower rate, $(\gamma + 1)(1 - \beta)$.

The implication is that high productivity thresholds lead to lower marginal costs and average shipping costs, should transport firms take into consideration factory prices. However at the same time transportation is perceived as being ever more costly as the share in the delivered price of the good increases concurrently. The quantity transported overall decreases with some friction and the per unit savings on the route between i and j are minimised, with the opposite holding true. In the limiting case where β tends to unity, transport firms absorb fully the factory price of the good and the attenuation is maximised, leading to the complete absorption of the increase in real shipping prices.

The intuition behind these results is as follows. The particular functional form of the shipping price imitates the behaviour of an additive formulation of transport costs as modelled in Hummels & Skiba (2004) and Hummels, Lugovskyy & Skiba (2009). Unfortunately the adoption of an additive form of shipping costs does not yield a closed form solution of the model (Irarrazabal, Moxnes & Opromolla 2014). Yet consistent with an additive formulation one can observe as factory prices of goods decrease (increase), the relative importance of shipping costs increases (decreases) as it constitutes a greater (smaller) percentage of the destination price of the good, all else equal.[14] A change in real shipping prices could also be perceived as exogenous adjustments to the markup set by the transport firm as a consequence of a change in the factory price of the good.[15]

[14]The elasticity of the destination price of a good with respect to the shipping price in an additive formulation of transport costs is the share of the shipping price in the destination price: $\frac{\partial p_{ij} f_{ij}}{\partial f_{ij} p_{ij}} = \frac{f_{ij}}{p_{ii}(\phi) b_{ij} + f_{ij}}$.

[15]Herein all markups are modelled as constant whilst under an additive costs' formulation the markup of the transport firm would become variable.

Turning to the equilibrium productivity threshold and export levels of incumbent transporters, there are elastic impacts following changes in trade costs. Compared to the Chaney (2008) model of trade these elasticities are amplified because trade costs are partly endogenised. Incumbent producers of varieties are now affected when the threshold changes as the shipping price is distorted, whilst in the original model constant returns to scale transport technology is assumed.[16] Herein, a lowering of the threshold decreases the market value of shipping prices. Incumbent producers are benefited as the real price of transport is low and exports increase, decreasing the average average cost of shipping. If transport firms set prices by invoking the factory price of the good, marginal costs increase and export levels rise yet at a lesser rate: Scale economies in transportation are dampened by this last effect.

Jointly changes in the threshold and the level of exports of incumbent transporters influence aggregate exports. As in the original version of the model, the extensive margin elasticity dominates the intensive margin elasticity. Through equation (3.9) a reduction in a variable trade barrier lowers the threshold and exports of new firms contribute to aggregate exports by $\gamma - (\sigma - 1)$. This entry of firms subsequently drives down the shipping price by $(\gamma+1)(\beta-1)$ which further decreases the threshold by $\frac{1}{1+(\gamma+1)(\beta-1)} > 1$, whilst in the original model no such propagation is materialised. Incumbent exporters do not affect the real shipping price, yet they are also benefited as they pay less for transportation. The level of exports increases by $(\sigma - 1)\frac{1}{1+(\gamma+1)(\beta-1)} > 1$ per cent. As the extensive margin dominates, the impact on aggregate exports is governed by the degree of a sector's heterogeneity and the propagating effects of transportation.

With respect to changes in fixed costs of exporting, equation (3.10) describes an amplification of the extensive margin elasticity which operates through the same channel as a change in a variable trade barrier: A decrease in fixed costs lowers the threshold and the set of exporting firms increases. At the intensive margin however, the results depart from the original version of the model wherein the impact is zero. As fixed costs decrease, real shipping prices decrease benefiting incumbent exporters solely through changes in the shipping price. Once again the extensive margin dominates and the impact on aggregate exports is driven by changes in the set of exporting firms following adjustments in fixed costs of exporting and real shipping prices.

The model is restrictive because *i*) the transport sector is closed and transport workers do not have the incentive to move to other sectors and vice versa; *ii*) all wages are normalised in the world; *iii*) the markups of transportation are invariable; *iv*) there are no adjustments in transport supply which is highly inelastic due to lengthy shipbuilding times which are not taken into account in this one-period model (see for example Kalouptsidi (2011)).

[16]That is, the shipping price is equal to the marginal cost which is the variable trade cost associated with distance to the destination.

These are additional channels of causation that have been shut down in order to highlight some bare bones characteristics of transportation: That the commercial practice of homogenised cargo space, the presence of scale economies in transportation and the pricing behaviour of transport firms all play a role in amplifying the gains, losses and distributional impacts identified in the literature on firm heterogeneity. By allowing such causation channels in the model, the number of determinants of shipping prices increase and interactions with tariffs become more blurred converging to the stylised facts discussed in Hummels (2007). This leads to interesting extensions which are the focus of future work.

The amplification mechanism proposed herein, arising from the functional form of transport costs, contributes to the body of literature that explains the empirically large coefficients representing the elasticity of import demand.

Hummels (2001) provides elasticity estimates for 41 two digit SITC goods with an average elasticity of substitution standing at 9.3. Large estimates are also reported in Clausing (2001), Head & Mayer (2002), Anderson & van Wincoop (2004) and Romalis (2007). In Baier & Bergstrand (2001), jointly trade liberalisation episodes and declines of transport costs explain 34% of the post-war growth in world trade. Yi (2003) mentions that there is a puzzle when trying to reconcile the constant 2-3% post-war annual trade growth with only an 11% reduction in trade barriers over the period, a relationship which is additionally non-linear. Chaney (2005) finds empirical support that the elasticity of aggregate exports with respect to variable trade barriers is equal to the degree of firm heterogeneity. In absolute value, this is always larger than the elasticity of aggregate exports with respect to trade barriers of models with representative firms. In the data used for this study, the elasticity of substitution estimated for each six digit subheading averages 3.55 (standard deviation 4.74 and median 2.6 for year 2006) corroborating the aforementioned findings.[17]

The theoretical framework of this study provides a justification for such large estimates by accounting for adjustments in transport technology. The fact that changes in the average prices of varieties induce changes in the marginal costs of the transport firm affects the per unit cost of shipping, all else constant. Because the transport industry, and predominantly maritime transport which is responsible for the carriage of 99% of the world's trade by weight and 90% of the volume of world trade, is characterised by increasing returns (Hummels (2007); OECD (2008)), the growth of the extensive margin[18] over the post-war period (Ruhl 2008) leads to more increased route savings because of stronger scale effects. These are alleviated however if transport firms take into consideration the factory prices of goods when formulating their optimal shipping price. The implication is therefore that tariff reductions can set off a string of beneficial

[17] See Appendix B.4 for the procedure yielding a distribution of price elasticities of import demand.

[18] Or in other words, the expansion of variety of traded goods.

impacts through the complementarity with transportation explaining thus these large observed estimates of trade costs, as the following section analyses.

Our paper also illustrates how incorporating a simple structural form for transport costs can have profound effects on canonical heterogeneous firm trade models. As Costinot & Rodríguez-Clare (2013) state, the derived gravity equations in the alternative micro-founded models of trade such as Eaton & Kortum (2002), Anderson & van Wincoop (2003), Bernard, Eaton, Jensen & Kortum (2003), Chaney (2008) and Eaton, Kortum & Kramarz (2011) have the same macroeconomic structure and subsequently same predictions regarding the effects of bilateral costs on bilateral trade flows. By embedding a structural form for transport costs in these models the microeconomic foundations are altered, hence an examination of whether the macroeconomic gravity structures convergence to the same predictions is required.

Indeed Arkolakis, Costinot & Rodriguez-Clare (2012) show that such models share similar welfare predictions –provided there are no intermediate traded goods or multiple sectors– that are determined by two principal statistics, the share of income expenditure on domestic goods and the elasticity of imports with respect to trade costs. If however the elasticity of imports with respect to trade costs is distorted by the presence of a transport sector, as we propose, welfare gains will once again depend on the specific model's microeconomic foundations and the interaction between manufacturing and transport firms. In the special case of a Pareto productivity distribution, by invoking Proposition 5 of Melitz & Redding (2013) we can state that a tariff reduction in the presence of a transport sector generates higher welfare gains than the heterogeneous firm model with no transport sector and the homogeneous model consisting of exporting and non-exporting firms with no transport sector. To achieve the same welfare gains in all three models requires, respectively, incrementally larger reductions in the heterogeneous firm model with no transport sector and the extended homogeneous model with no transport sector. The case of an extended homogeneous firm model with a transport sector which is compared to the heterogeneous trade model with a transport sector does not alter the Proposition: Because in the latter model there are endogenous selection responses to tariffs and transport costs which cause changes in the average productivity of exporting and non-exporting firms, there are higher welfare gains from tariff reductions compared to the former model which has no such margin of adjustment.

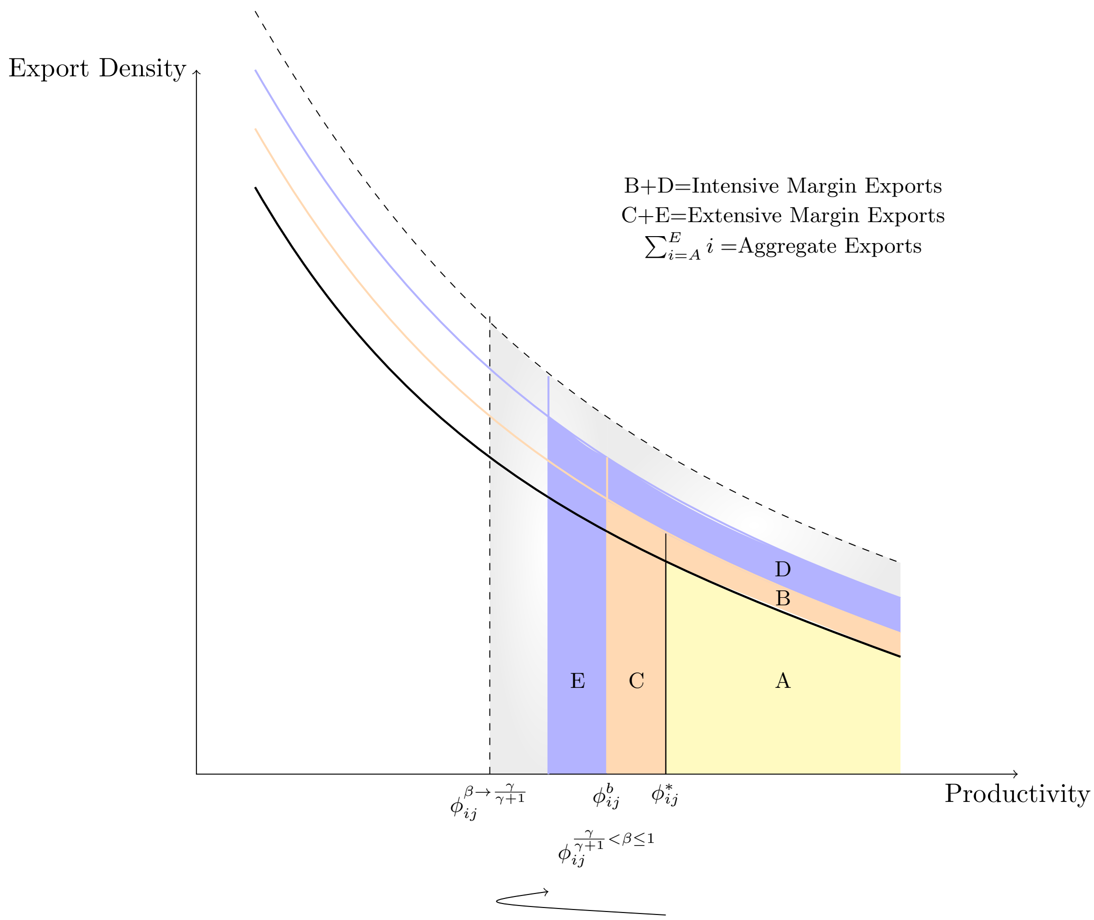
3.3.7 The implications of trade liberalisation

This model contains an endogenous relationship of transport costs and goods' prices, yet all other trade costs contained in the vector b_{ij} are considered exogenous. A change in an element of this vector, for example a tariff reduction, affects both trade margins directly and because of the endogenous relationship there are also indirect effects through the adjustment in the shipping price.

Commencing with a 1 per cent reduction in b_{ij}, there ensues a 1 per cent reduction in the productivity threshold ϕ^*_{ij} which shifts to ϕ^b_{ij} in Figure 3.1. As new firms participate in exporting, the average factory price of the good increases by $\gamma+1$ per cent. Transport firms receive the consignments and yield the shipping price based on the number of items comprising the consignment and/or the weight and its declared value. The set price is a percentage of the factory price of the average exported variety, thus the market value of the shipping price is the same across varieties of a sector. Because the sector's aggregate price increased, the real shipping price across varieties goes down and the productivity threshold attains the westernmost limit on the horizontal axis of Figure 3.1. However, the more the transport firm is influenced by the factory price of the good when deciding the optimal shipping price, such as additional packaging costs or insurance costs, the marginal costs of shipping go up by β dampening the overall decline in shipping prices. Thus the vector of trade costs τ_{ij} decreases allowing for disproportionately more firms to commence exporting by virtue of a lower productivity threshold which lies in between the permissible range of productivities ϕ^b_{ij} and $\phi_{ij}^{\beta\to\frac{\gamma}{\gamma+1}}$ of Figure 3.1.

The disproportionately large number of firms that begin to export contribute to total

Figure 3.1: Implications of trade liberalisation



exports $\frac{\gamma-(\sigma-1)}{1+(\gamma+1)(\beta-1)}$ per cent represented by adding segments C and E of the figure. The value of exports of incumbent firms has increased by $\frac{\sigma-1}{1+(\gamma+1)(\beta-1)}$ per cent or the area under B and D. Both elasticities can be decomposed to the direct effect of a 1 per cent reduction of b_{ij} increasing exports by $\gamma-(\sigma-1)$ and $\sigma-1$ per cent respectively, and the reduction in shipping prices which further causes exports to increase by $\frac{1}{1+(\gamma+1)(\beta-1)}$ per cent. Hence there is a more elastic impact compared to the Chaney (2008) and Krugman (1980) models of trade. With respect to the latter the only adjustment would occur through the intensive margin and exports would increase by the shaded area labelled B. Concerning the former, the total increase in exports after adjustments in both margins would be represented by the area under C and B.

While an exogenous reduction in the marginal cost of transport has equivalent effects in magnitude, the channel of causality is altered. Assuming a 1 per cent reduction in d_{ij}, the shipping price is lowered by 1 per cent. The productivity threshold is affected as it decreases by 1 per cent which in turn further lowers the shipping price by $(\gamma+1)(\beta-1)$ per cent affecting one final time the productivity threshold, reducing it by $\frac{1}{1+(\gamma+1)(\beta-1)}$ per cent.

Incumbent exporters are impacted directly by the 1 per cent decrease in d_{ij}, and raise their exports by $\sigma-1$ per cent. The shipping price adjustment following changes in the productivity threshold increases additionally exports by $\frac{1}{1+(\gamma+1)(\beta-1)}$ per cent. Jointly the contribution of the two margins and the domination of the extensive margin leads to the amplified impact on aggregate exports.

These observations constitute this paper's contribution to the literature explaining the large empirical estimates of the elasticity of import demand. In addition to the robust explanations provided by Yi (2003) and Ruhl (2008), we propose that trade liberalisation events may lead to beneficial adjustments in transport technology that spur additional knock on effects on trade.

The former paper suggests that vertical specialisation can initiate a chain of declines in costs and prices following an initial tariff reduction and goods become gradually more vertically specialised, reinforcing this effect in a nonlinear fashion. The latter study proposes that trade liberalisation is a typically permanent change and so are the corresponding shocks to productivity and demand. Such a change ensures that the future value of exporting in all states is increased and extensive margin growth is large. If the contribution of the extensive margin is not controlled for, then trade liberalisation appears to affect trade flows in a disproportionately large manner.

This paper puts forward that there is a complementarity between tariff and transport costs reductions in the presence of scale economies in transportation. A trade liberating event prompts extensive margin growth, reducing the per unit cost of shipping. Transport firms post lower shipping prices but if packaging or insurance costs are large this price may be dampened, depressing the per unit reduction in shipping costs. By not accounting for this complementarity, the standard trade models of representative and heterogeneous firms are not able to decompose the overall reduction of the iceberg cost τ_{ij} into tariff and transport effects, hence the estimated elasticity appears to be large.

The following section presents the supporting evidence for such complementarities. Since shipping prices exhibit significant impacts in both margins of trade and $\beta - 1$ is shown to be quantitatively important, the tariff elasticity is also affected because at the aggregate, the estimated elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ matters for the whole vector of trade costs τ_{ij}.

3.4 Empirical Strategy and Identification

The empirical strategy is to detect whether tariff cuts create disproportionately large elasticities due to, predominantly, extensive margin growth which induces stronger scale effects and relatively less costly transport services. To this effect aggregate trade and transport cost data are employed, classified using the Harmonized Commodity Description and Coding System at the six digit aggregation level.

For expositional convenience a sector h and a particular six digit category of commodities will be equivalent definitions. Identifying separately the parameters β_h and γ_h becomes difficult due to the aggregate nature of the data. It will suffice to identify the negative impact of $\frac{\gamma_h}{1+(\gamma_h+1)(\beta_h-1)}$ on aggregate exports, under the null hypothesis that this elasticity is zero.

This is achieved by undertaking a four step procedure based on Hummels & Skiba (2004), Lugovskyy & Skiba (2011), Helpman, Melitz & Rubinstein (2008), Crozet & Koenig (2010) and Chaney (2005). The first step transforms the per unit element of shipping prices into its ad valorem equivalent in order to infer, on aggregate, if and how factory prices of the good impact on the latter.

The second step introduces a latent variable that is greater than unity if variable profits, calculated using the predicted values of ad valorem shipping prices from the previous step, are greater than fixed costs. It permits calculation of the probability of a country's sector to export to a specific destination, conditional on the observed variables.

Subsequently the predicted probabilities which, under the Pareto distribution assumption, will be distributed with shape parameter γ, lead to the estimation of the trade cost specific elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ for each of the $h \in H$ sectors.

In the last step, the distribution of the trade cost specific elasticities, are tested for their joint interaction with variable trade costs indicating their (non-)zero impact on aggregate trade flows.

- ***Step 1: Transforming per unit to ad valorem shipping prices***

The target is to derive expression (3.2), which is the outcome of a transformation from per unit to ad valorem shipping prices where the elasticity of interest is $\beta_h - 1$. Based on Lugovskyy & Skiba (2011), ad valorem shipping prices will consist of a multiplicative part and a specific part measured in per unit terms. Due to the aggregation level and as the theoretical part showed, these shipping prices become sector specific rather than variety specific. A strong assumption at this point is that all multiplicative parts are an element of the vector of trade costs b_{ij} and do not enter the transformation. Shipping prices can be expressed as:

$$p_{iih} f^A_{ijh} = p_{iih} + s^U_{ijh}$$

where A and U denote ad valorem and the per unit specific part respectively. Hummels & Skiba (2004) mention how the per unit element is possibly dependent on prices as well as a vector X of non price factors comprising the marginal costs of transport. Denoting the possible dependence on sectoral prices by an elasticity β_h we can thus rewrite the above relationship for a specific sector as $\tilde{f}_{ijh} \equiv f^A_{ijh} - 1 = p^{\beta_h - 1}_{iih} \times X_{ijh}$. If marginal shipping costs consist only of distance to the destination d_{ij} and the volume of goods transported q_{ijh}, the resulting estimable relationship becomes in logarithmic form:

$$\ln \tilde{f}_{ijhm} = \delta_0 + (\beta_h - 1) \ln p_{iih} + \delta_1 \ln d_{ij} + \delta_2 \ln q_{ijhm} + \epsilon_{ijhm}$$

where m denotes the mode of transport. The error term ϵ_{ijhm} reflects unobserved shocks in transportation, specific to country pairs ij, and within each country pair, modes m and sectors h. This equation is similar to the one estimated in Hummels & Skiba (2004) and entails simultaneity between shipping prices, factory prices and traded quantities.

For a particular year, the parameter estimate of $\beta - 1$ is identified when it is derived using only the variation across sectors and destinations for each exporter. Since the latter form of variation is constant, there is variation of log factory prices occurring across exporters within a sector and across sectors within an exporter. Using an exporter fixed effect we are left with variation across sectors for each exporter which is adequate in the data, with standard deviation averaging about 1.7.

A negative estimate of δ_2 identifies the presence of scale effects in transportation. It is required that the estimate is derived using variation across importers for each exporter-sector-mode. For each exporter-sector-mode the larger the quantity shipped to a destination, the more achievable are scale effects. By taking the mean difference $\ln q_{ijhm} - \overline{\ln q}_{ihm}$ we can rule out influence from variation across sectors or exporter-sectors.

Under the same rationale, pairwise specific log distance is differenced from each exporter's mean: $\ln d_{ij} - \overline{\ln d_i}$. The equation obtains its estimable form:

$$\ln \tilde{f}_{ijhm} = \delta_0 + (\beta - 1)\ln p_{iiht} + \delta_1 \left(\ln d_{ij} - \overline{\ln d_i}\right) + \delta_2 \left(\ln q_{ijhm} - \overline{\ln q}_{ihm}\right) + \sum_i \alpha_i + \sum_m \alpha_m + \epsilon_{ijhmt} \quad (3.11)$$

Where α_i and α_m capture the variation arising across exporters and across modes.

After estimating the model the following tests are performed:

- $H_0 : \widehat{\beta - 1} = -1$: Transport firms do not take into consideration the factory price of the good, and enjoy full scale effects benefits if $\hat{\delta}_2 < 0$.
- $H_0 : \widehat{\beta - 1} = 0$: Transport firms absorb 100% of the price of the good, and destroy any beneficial impacts from scale effects if $\hat{\delta}_2 < 0$.

The simultaneity in equation (3.11) is dealt with by using lags of the independent variables as instruments. Contrary to Hummels & Skiba (2004) we do not use tariffs as an instrument, because in the subsequent steps, tariffs together with predicted shipping prices cause the probability to export and the level of exports, generating high correlation among the independent variables. The predicted values of shipping prices, denoted as $\widehat{\ln \tilde{f}}_{ijhm}$, are then incorporated in step 2.

- ***Step 2: Export participation***

Based on Helpman, Melitz & Rubinstein (2008), export participation in a specific sector h can only be inferred if variable profits of the firm, $r_{ijh}(\phi)/\sigma$, exceed fixed costs F^m_{ijh}. Defining the latent variable Z_{ij}, the ratio of variable profits to fixed costs within each sector is such that:

$$Z_{ij} \equiv \frac{r_{ij}(\phi)/\sigma}{F^m_{ij}} = \frac{L_j\,[P_j]^{\sigma-1}\,\tau_{ij}^{-(\sigma-1)}\phi^{\sigma-1} \times \lambda_7}{F^m_{ij}},$$

where λ_7 is a constant.[19] Firms that are more productive, or the larger the trading partner, the nominator becomes greater than the denominator and vice versa. Observed positive exports at the aggregate six digit level have occurred because firms in h are characterised by $Z_{ij} > 1$.

Ad valorem trade costs τ_{ijh} consist of the element b_{ijh} which will be assumed to be an ad valorem tariff on the exported good, and shipping prices $\tilde{f}_{ijhm}$. The above equation becomes in logarithmic form:

$$\ln Z_{ijh} = -(\sigma - 1)\ln b_{ijh} - (\sigma - 1)\widehat{\ln \tilde{f}}_{ijhm} + \sum_i \alpha_i + \sum_j \alpha_j + \zeta_{ijh},$$

[19] $\mu \left(\frac{\sigma}{\sigma-1}\right)^{-(\sigma-1)} \frac{1}{\sigma}$.

where ζ_{ijh} is an iid shock that occurs within country pairs. Denoting this export decision with a binary indicator I_{ijh}, the logistic equation is:

$$Pr(I_{ijh} = 1|\Psi) \equiv \Lambda\left(-\delta_3(\sigma - 1)\ln b_{ijh} - \delta_4(\sigma - 1)\widehat{\ln \tilde{f}}_{ijh} + \sum_i \alpha_i + \sum_j \alpha_j + \zeta_{ijh}\right) \tag{3.12}$$

where Ψ denotes the observable variables and $\Lambda(\cdot)$ denotes the cumulative logistic distribution function.

The binary response whether firms in sectors are able to export given a particular level of (predicted) transport costs and/or tariff levels becomes difficult to answer. Transport costs and/or tariffs may be large, yet export levels can be finite and large in the data using this particular aggregation level. Plausible explanations are unobserved trade costs that are pairwise specific contained in the error term and/or the size of the countries trading. In fact the sample rarely has a zero value of exports for high finite transport costs and tariffs. To censor the sample, we rely on the following assumption: Exports of a particular sector k from country i to j are considered minimal or zero if shipping prices and tariffs exceed the 75th percentile (≥ 0.08 and ≥ 0.14, respectively for year 2006). Approximately 6.83% of exports across country pairs in the sample fail this threshold. The average of the pairwise specific share of exports relative to total exports is 0.49% (standard deviation 5.16), which makes the assumption somewhat innocuous: Sectors which face generally high trade costs tend to exhibit relatively low trading volumes.

One expects to infer that increases in tariffs and shipping prices decrease the probability of exporting. Yet, changes in factory prices that affect shipping prices can also impact the probability of exporting. This dependence is understood by the predicted values of shipping prices derived from step 1.

This specification, along with the equivalent specifications used in Helpman, Melitz & Rubinstein (2008) and Crozet & Koenig (2010), are exposed to the incidental parameter problem[20] as documented in Charbonneau (2012) which is caused by the use of multiple fixed effects in non-linear models. In particular, Greene (2002) states that the maximum likelihood estimator with fixed effects is inconsistent, because the asymptotic variance of the estimator of the main parameters is a function of the small and assumed fixed group size. In addition small sample bias could be present. Since there exists conflicting evidence about the magnitude of the bias for the probit model (Greene 2002) we abstain from its use. As the group size is not constant in the dataset it invalidates the use of a conditional logit model that would lessen the problem (Charbonneau 2012). Hence we employ a simple logit model yet acknowledging the fact that the results may be biased and inconsistent, given the panel length.[21]

[20] For a discussion and proposed solutions of the incidental parameter problem the reader is referred to Neyman & Scott (1948) and Lancaster (2000).

[21] 9 exporters trading with 36 importers are considered in the second stage.

- ***Step 3: Obtaining sectoral elasticities***

It will be useful for notational convenience to denote the inverse of productivity as $\omega = \frac{1}{\phi}$. Similar to Crozet & Koenig (2010), by invoking the definition of the Pareto distribution and the equilibrium export decision (3.6), the probability of country-sector ih's firms exporting to country j is:

$$Pr\left(\omega_{ijh} < \omega^*_{ijh}\right) = \left\{ \left[\frac{L_j}{L}\right]^{\frac{1}{\gamma}} \left[\frac{b_{ijh} d_{ij}}{\theta_{jh}}\right]^{-\frac{1}{1+(\gamma+1)(\beta-1)}} \left[F^M_{ijh}\right]^{-\frac{1}{\sigma-1}\frac{1}{1+(\gamma+1)(\beta-1)}} \times \lambda_3 \right\}^{\gamma}$$

The left hand side of the above relationship can be approximated by the predicted probabilities of relationship (3.12). Writing the above expression in logarithmic form and replacing the log predicted probabilities, while controlling for exporter and importer specific variation for each sector, one obtains:

$$\ln \widehat{Pr}(I_{ijh} = 1|\Psi) = \delta_0 - \left[\frac{\gamma}{1+(\gamma+1)(\beta-1)}\right]_{b_{ijh}} \ln b_{ijh} - \left[\frac{\gamma}{1+(\gamma+1)(\beta-1)}\right]_{d_{ij}} \ln d_{ij} + \sum_i \alpha_i + \sum_j \alpha_j + \xi_{ijh}, \text{ for each } h \in H \tag{3.13}$$

The resulting relationship yields the trade cost specific estimate of $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ for a particular sector. One can use a least squares estimator within each sector at the six digit level in order to obtain a distribution of the elasticities across sectors for tariffs and distance to the destination. A limitation occurs as some sectors contain very few observations of partners trading and degrees of freedom cannot be obtained. Carrying out the estimation for each four digit level of aggregation solves this problem, albeit with some loss of accuracy as the estimate of $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ is the same across a number of sectors under a respective four digit header.

- ***Step 4: Impacts on aggregate trade***

In the final step we state the null hypothesis of whether the elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ is zero. With reference to specification in Chaney (2005) and the equilibrium equation of aggregate trade (3.8) the estimable equation for accommodating this hypothesis is:

$$\ln X_{ijhm} = \delta_0 + \delta_5 \ln b_{ijh} + \delta_6 \left[\widehat{\frac{\gamma_h}{1+(\gamma_h+1)\beta_h}}\right]_{b_{ijh}} \ln b_{ijh} + \delta_7 \ln d_{ij} + \delta_8 \left[\widehat{\frac{\gamma_h}{1+(\gamma_h+1)\beta_h}}\right]_{d_{ij}} \ln d_{ij} + \sum_i \alpha_i + \sum_j \alpha_j + \sum_h \alpha_h + \sum_m \alpha_m + \eta_{ijhm} \tag{3.14}$$

where the joint impact of $\hat{\delta}_5$, $\hat{\delta}_7$ and their respective interactions are tested for their equality to zero. Based on the aggregate trade equation (3.8) we expect the signs of the interaction terms' coefficients to be negative and increasing in γ in absolute value. Should they be significantly different from zero, the null hypothesis is rejected leading to three conclusions. First that the presence of a transport sector has distorting impacts on aggregate trade flows as shipping firms may take into consideration the factory price of the good and operate under increasing returns. Second that tariff reductions and shipping prices go hand in hand generating an amplified elasticity of trade costs. Lastly, this four step procedure taken with a pinch of salt due to the potentially biased and inconsistent estimates arising in step 2, provides a solution for decomposing the complementarity between tariffs and shipping prices, thus explaining the reason for the observed high estimates of trade cost elasticities present in empirical gravity equations.

3.5 Construction of the Dataset

For the first step of the empirical procedure the OECD Maritime Transport Costs Database is utilised which contains information on ad valorem and per unit shipping prices as well as the quantity transported by various modes of ocean transport. These are expressed at the HS 1988/1992 6 digit aggregation level for the years 1991-2007. Factory prices come from the CEPII Trade Prices dataset and are expressed at the HS 1996 revision at the same aggregation level. We proceed to apply the conversion to the 1992 revision for each of the 5,130 categories of goods. The conversion leads to some loss of information as there are 116 categories of goods at the HS 1992 revision that have two or more HS 1996 corresponding goods, therefore these commodities will be excluded from the analysis.

For the second, third and fourth steps, preferential (AHS) simple average tariffs are used which are extracted from the WITS TRAINS dataset of the World Bank. Tariffs are expressed at the HS 1988/1992 digit level. Exports and traded quantities are obtained from the UN Comtrade database at the same aggregation level and revision number. Tariffs are expressed in ad valorem equivalent terms, exports are expressed in US Dollars and quantities in kilograms. For geographical trade barriers such as distance to the destination the CEPII Geodist dataset is invoked.

The datasets cover the period from 1991 to 2007 and we observe nine different exporters trading with thirty six importers, which are detailed in Appendix B.2. A limitation of the OECD Maritime Transport Costs dataset is that one cannot observe EU 15 countries separately and it is hence excluded from the estimation procedure. All estimations are cross-sectional for year 2006.

Table 3.1: Impacts on ad valorem shipping prices

VARIABLES	(OLS) Ad valorem shipping prices	(IV) Ad valorem shipping prices	(IV) Ad valorem shipping prices
F.O.B. price	-0.277***	-0.284***	-0.272***
	(0.003)	(0.006)	(0.011)
Distance	0.091***	0.105***	0.11***
	(0.007)	(0.014)	(0.023)
Quantity transported	-0.015***	-0.03***	-0.038***
	(0.001)	(0.004)	(0.007)
	Fixed Effects		
Importer	N	N	N
Exporter	Y	Y	Y
Sector	N	N	N
Mode	Y	Y	Y
Observations	42,374	11,862	4,195
R-squared	0.271	0.268	0.286
Hausman p-value		0	0.01
Hansen p-value			0.13
$\widehat{\beta - 1} = -1$ p-value	0	0	0
$\widehat{\beta - 1} = 0$ p-value	0	0	0

Cross sectional OLS/IV estimates for year 2006, monetary units are constant U.S. Dollars. Errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. For column (2) price and quantity are instrumented by their first lag respectively. For column (3) price and quantity are instrumented by their first and second lags respectively.

3.6 Estimation Results

- ***Step 1: Transforming per unit to ad valorem shipping prices***

Table 3.1 presents the outcomes of estimating equation (3.11). Column (1) contains the OLS regression estimates and columns (2) and (3) report the IV estimates using one and two sets of lagged values of factory prices and quantities respectively.

The findings are in line with those of Hummels & Skiba (2004) whereby the quantity transported has a negative coefficient and distance has a positive coefficient in all experiments. Distance has an effect that is similar in magnitude to the extant literature on transport costs (Clark, Dollar & Micco 2004). The negative coefficient of quantity transported confirms the presence of scale effects in maritime transportation in agreement to Clark, Dollar & Micco (2004) and Martinez-Zarzoso & Suarez-Burguet (2005) who observe similar findings. The elasticity of shipping prices with respect to factory prices is negative in all instances, implying an average value of β equal to 0.722 less than the unitary elasticity which is significantly different from one or zero.

The positive sign of β was suspect since there is a positive and significant relationship between per unit transport costs and factory prices as Hummels & Skiba (2004) which is also verified herein using an alternative specification presented in Appendix B.3 to document the complementarity between transport costs and tariffs. Their reported elasticity, β, averages 0.625 for a set of six importers and worldwide exporters.

Such a result confirms that factory prices of goods exhibit a partly positive impact on ad valorem shipping prices. An increase in the factory price reduces the ad valorem shipping price since, all else constant, $\frac{\partial f_{ij}}{\partial p_{ii}} \frac{p_{ii}}{f_{ij}} = -1$ hence the negative signs in columns (1), (2) and (3). The elasticity should be also unit elastic yet the associated null hypothesis is rejected: Transport firms incorporate information about factory prices of goods in their marginal cost, causing a dampening effect which reduces the elasticity in absolute value terms.

In conjunction with the negative coefficient on the quantity transported, it is concluded that transport firms are enjoying cost saving benefits from scale effects yet these benefits are dampened since they also consider factory prices of goods in their cost function.

The implication is, as illustrated in the subsequent steps, that predicted values of shipping prices, which are determined by factory prices, quantities transported and distances to the destination have quantitatively important influence on the probability to export and aggregate exports.

- ***Step 2: Export participation***

How do increased factory prices, scale effects, distance to the destination or tariffs impact export participation? In this study, changes in the first three variables affect shipping prices and indirectly affect the probability of a sector's exports. Changes in the latter influence directly a sector's exports.

An initial glance reveals that a sector's exports from country i to j that faces tariffs and shipping prices above the 75th percentile tend to have a very small share (0.49% on average, standard deviation 5.16) in total sectoral exports from i to j. This is represented effectively as a decision not to export, given the data weakness that shipping prices are observed only for finite values of exports at this aggregation level.

The estimates of equation (3.12) are presented in Table 3.2. Each column corresponds to the predicted values of shipping prices that are derived from the least squares regression and the instrumental variables regressions with no and one overidentifying restriction of Table 3.1.

The coefficients are all significant and have the expected signs. A unit decrease in shipping prices increases the probability of exporting to j by 0.004 on average across columns, holding the tariff variable at its mean. A unit decrease in tariffs increases the probability of exporting to j by 0.017 on average across columns, holding shipping prices at their mean. Although not directly comparable, the estimated coefficients have the same signs but lower marginal effects in absolute value to those of Helpman, Melitz &

Table 3.2: Export participation

Variable	(1) Logit Export Participation	(2) Logit Export Participation	(3) Logit Export Participation
Shipping price (Predicted)	-1.573***	-1.533***	-1.545***
	(0.146)	(0.14)	(0.137)
Tariff	-5.607***	-5.567***	-5.571***
	(0.423)	(0.421)	(0.421)
	Fixed Effects		
Importer	Y	Y	Y
Exporter	Y	Y	Y
Sector	N	N	N
Observations	20,223	20,223	20,223
R-Squared	0.416	0.416	0.415

Cross sectional logit estimations for year 2006. Errors are allowed to be correlated within country pair clusters. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1)-(3) follow from the respective OLS/IV estimations presented in Table 3.1.

Rubinstein (2008). They are also lower in absolute value compared to Crozet & Koenig (2010), who report an average coefficient of 1.29, but the variance of the results across sectors is large. The low marginal effects, yet significant, could be attributed to the imposed assumption for censoring the sample and/or the incidental parameter problem resulting in biased and inconsistent coefficients.

Bearing this in mind, it is concluded that increases in factory prices reduce shipping prices by $(\beta - 1)\%$ and the probability to export increases following the decline in the real price of transport. An increase in the quantity shipped induces greater scale effects, reducing shipping prices and increasing the probability to export. A similar effect is observed following a reduction in the distance to the destination. The indirect channel of causation is not possible to be traced when estimating the impact of transport costs using a distance-based measure as a proxy. The latter would have a direct impact as tariffs exhibit in this specification.

The predicted probabilities corresponding to each column will be used as the dependent variable in step 3, in order to obtain the magnitudes of $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ for each six digit sector within a country pair.

- ***Step 3: Obtaining sectoral elasticities***

Similarly to Crozet & Koenig (2010) the effect of distance and tariffs on the log probability to export is estimated utilising the importer-exporter-sector specific predicted probabilities of the logit estimations. Estimating equation (3.13) for each four digit sector yields a trade cost specific estimate of $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ that is common for each six digit sector under the four digit heading.

The procedure is applied to all variants of the log predicted probability distribution stemming from the OLS and IV estimations, using a fixed set of rules for all four digit headings: First, regressions that have a p-value of the F-statistic greater than 5% are removed from the sample as not being able to explain the variability in the data. Coefficients which have a p-value of the t-statistic greater than 5% are not considered.

The first operation disregards 111 out of 358 observations on average across the three experiments and the second disregards 160 observations. 87 elasticities remain, each corresponding to a four digit heading. The results, plotted in panels 3.3-3.4 and 3.5-3.7 indicate that the average elasticity is negative, inelastic and the distribution has a thick left tail, which seems somewhat to support the theory. These remarks fit the tariff elasticities of $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ more appropriately compared to the distance elasticities which have 12 positive observations out of 87 (as opposed to 2 for tariffs). Plausible explanations could be evidence of misspecification or measurement error arising from the aggregation and the previous steps.

In panels 3.3-3.4, the mean of the distance specific distribution of $\frac{1}{1+(\gamma+1)(\beta-1)}$ is -0.045 (standard deviation 0.23) while the corresponding values for the tariff specific elasticities in panels 3.5-3.7 are -0.17 (standard deviation .29).

The approach is reminiscent of Crozet & Koenig (2010) who utilise firm level data in order to identify γ across a set of commodity categories, where the mean value is 10.76 when imposing no assumption on transport technology except that it is constant returns to scale. While the current procedure is not able to separately identify β and γ, the estimated elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ of the two trade costs for each four digit heading could be tested for their joint impact on trade flows after they are allocated to the respective six digit sectors.

Distribution of $\left[\widehat{\frac{\gamma}{1+(\gamma+1)(\beta-1)}}\right]_{d_{ij}}$

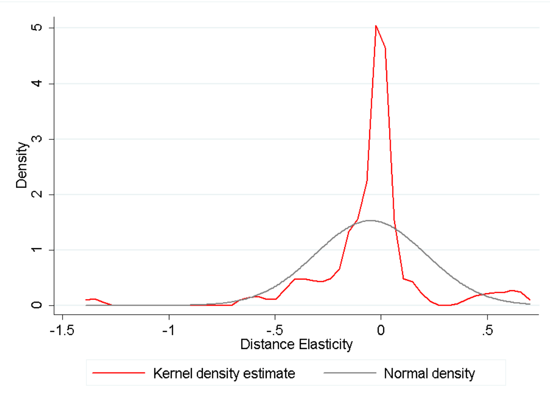


Figure 3.2: Stemming from OLS estimates of Table 3.1

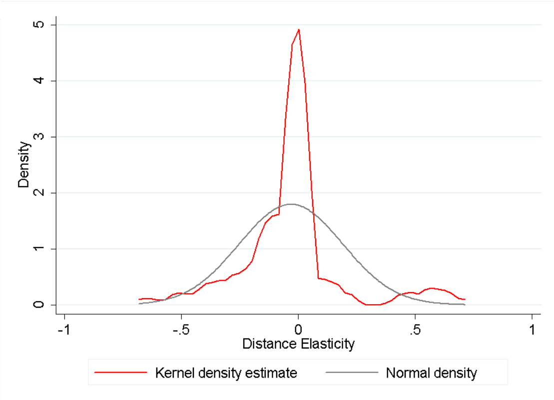


Figure 3.3: Stemming from IV estimates with no overidentifying restrictions of Table 3.1

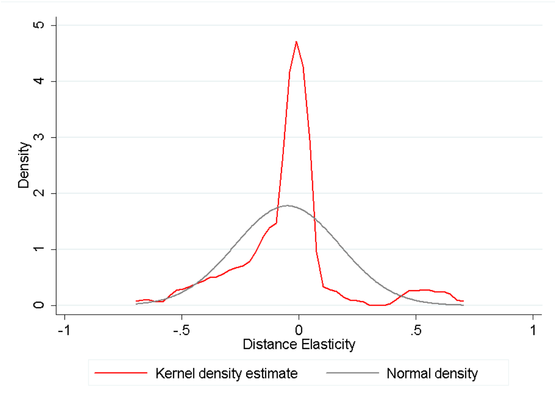


Figure 3.4: Stemming from IV estimates with two overidentifying restrictions of Table 3.1

Distribution of $\left[\widehat{\frac{\gamma}{1+(\gamma+1)(\beta-1)}}\right]_{b_{ij}}$

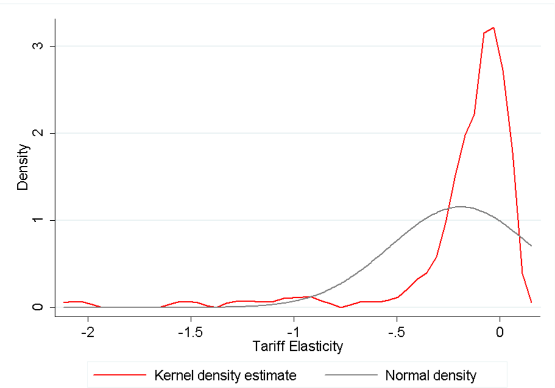


Figure 3.5: Stemming from OLS estimates of Table 3.1

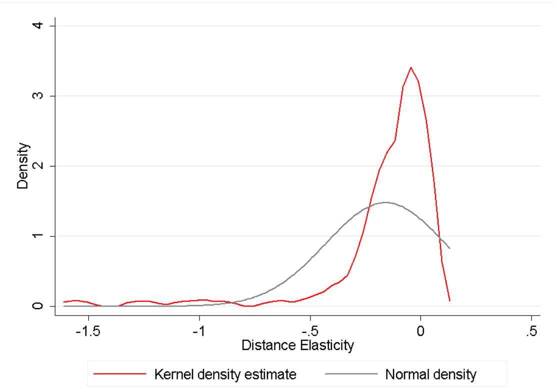


Figure 3.6: Stemming from IV estimates with no overidentifying restrictions of Table 3.1

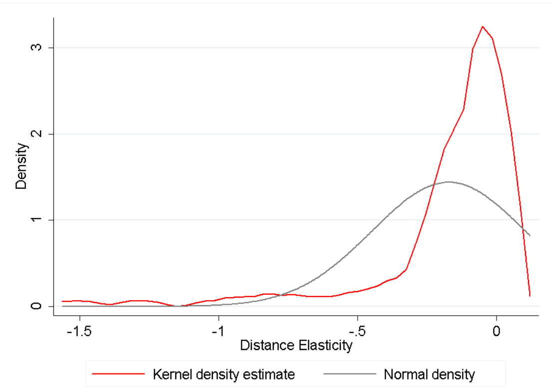


Figure 3.7: Stemming from IV estimates with two overidentifying restrictions of Table 3.1

Table 3.3: Impacts on aggregate trade

Variable	(1) OLS Exports	(2) OLS Exports	(3) OLS Exports	(4) OLS Exports
Tariff	-0.275***	-0.377***	-0.376***	-0.374***
	(0.116)	(0.126)	(0.125)	(0.127)
$\left[\widehat{\frac{\gamma}{1+(\gamma+1)(\beta-1)}}\right]_{b_{ij}} \times$ Tariff		-0.583***	-0.67**	-0.731**
		(0.240)	(0.206)	(0.275)
Distance	-0.747***	-0.758***	-0.767***	-0.759***
	(0.211)	(0.216)	(0.214)	(0.214)
$\left[\widehat{\frac{\gamma}{1+(\gamma+1)(\beta-1)}}\right]_{d_{ij}} \times$ Distance		-0.085	-0.127	-0.169
		(0.417)	(0.510)	(0.508)
Fixed Effects				
Importer	Y	Y	Y	Y
Exporter	Y	Y	Y	Y
Sector	Y	Y	Y	Y
Observations	5,063	5,063	5,007	5,091
R-Squared	0.526	0.527	0.526	0.53
Ho: $\delta_5 = \delta_6 = 0$ p-value		0	0	0
Ho: $\delta_7 = \delta_8 = 0$ p-value		0	0	0

Cross sectional OLS estimations for year 2006, monetary units are current U.S. Dollars. Standard errors are allowed to be correlated within country pair clusters. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (2)-(4) follow from columns (1)-(3) of Table 3.1.

- ***Step 4: Impacts on aggregate trade***

By obtaining the estimated elasticities from the previous section, we can test whether these have an impact on aggregate trade flows. The theoretical exposition asserts that if there is any impact, in the sense that $\beta - 1$ is significant as was confirmed in the first step, it should be negative and large. Therefore we expect a negative sign for the interaction term coefficients, however the magnitudes would be of no particular meaning. In order to obtain a true magnitude of the elasticity, a methodology similar to Helpman, Melitz & Rubinstein (2008) must be adopted using aggregate trade data. However if this procedure had been followed we would not have been able to identify the composition of the estimated elasticity and would be required to comment on the identification via the elasticity's magnitude.

Instead, by estimating relationship (3.14) which is equivalent to that of Chaney (2005), we observe if the identified elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)}$ is quantitatively important. This is done by using an interaction term of the elasticity variables with each trade cost and then testing for the joint significance of the interaction coefficient with the respective trade cost coefficient.

Table 3.3 illustrates the findings. In column (1) the impact of tariffs and distance on export flows is shown. The elasticities are significantly negative as economic theory predicts, yet the coefficient of distance can be regarded as being relatively low, compared to the sampled coefficients of Disdier & Head (2008).[22] In column (2) the interactions are introduced which originate from column (1) of the first step. While the theoretical prediction might be confirmed for tariffs, the same does not apply for distance as the interaction coefficient is insignificant. The same observation holds for columns (3) and (4) which consider the interaction variables that originate from the predicted values of shipping prices net of simultaneity.

The null hypothesis that the elasticity $\frac{\gamma}{1+(\gamma+1)(\beta-1)} = 0$ is rejected, which follows from the outcomes of the joint hypotheses tests $\hat{\delta}_5 = \hat{\delta}_6 = 0$ and $\hat{\delta}_7 = \hat{\delta}_8 = 0$. The theoretical prediction of the model at least for tariffs is thus confirmed. As the interaction coefficient of distance is insignificant, the result remains ambiguous for this variable.

Three general conclusions are reached. First, transportation matters: scale effects, distance, the factory prices of goods all seem to be elements of the marginal cost of shipping with significant effects. By using distance as a proxy for transport costs the empirical researcher is ignoring transport technology (Hummels & Skiba 2004) and ensuing indirect impacts on trade flows through the marginal cost of shipping.

Second, tariff reductions and shipping prices jointly impact the range of goods traded. Tariff reductions increase the probability of a sector to commence exporting to a particular destination. If this event occurred with a time lag or in a previous period, unequivocally the quantity transported must have increased in subsequent periods. Gradually, ceteris paribus, shipping prices are reduced (via step 1) increasing the probability to export. Hence there are indirect effects captured by the specification that confirm a perennial complementarity between tariffs and transport prices.

Third, the empirical strategy – albeit leading to results which need to be interpreted with some caution due to the aggregation level used and the potential biased and inconsistent estimates – seems to justify the high coefficients of trade liberalisation events or tariff reductions when transport costs remain unmodelled. The identification channel becomes hazy by not incorporating further assumptions about transport technology. The results presented herein are encouraging yet inconclusive. A validation or rejection of the findings could be attained by applying the procedure to a more disaggregated dataset, ideally at the firm level where the assumption in step 2 would be redundant, and a fixed group size could be more achievable.

[22] These are displayed in Figure 1 of their study.

3.7 Conclusion

In this paper transport technology is embedded in the Chaney (2008) model of trade. Transport firms provide services produced under increasing returns to scale, marginal costs are partly determined by the magnitude of the factory prices of exported commodities, and transport firms allocate the same freight rate for a range of traded commodities similar in their characteristics.

Trade liberalisation affects directly both trade margins as the standard model predicts. Due to the specific transport technology, complementarity with shipping prices arises creating indirect effects that propagate the impact of trade liberalisation. Extensive margin growth prompts increases in the quantity transported, lowering per unit shipping costs and the real shipping price. Should marginal costs of transport increase however because of additional weight placed on the factory price of transported goods, scale effects are dampened. By not assuming this interaction, standard trade models of representative and heterogeneous firms are unable to identify and decompose direct and indirect effects of trade liberalisation, resulting in observing large elasticities of import demand.

It is confirmed empirically that both freight rates and tariffs affect exports and the range of goods traded. An unequivocal rise in the quantity transported following a tariff reduction lowers the freight paid to transport firms, which is indeed stemmed if the influence of the factory price on the freight is large. It is inferred that there exists a perennial complementarity between tariffs and freight rates, leading to an amplified equilibrium elasticity of aggregate exports with respect to trade costs which is also quantitatively important.

The overshooting of tariff cuts' responses due to transport technology generate useful considerations regarding trade policy. Gains from trade following liberalisation such as extensive margin growth, reallocations of resources and increased efficiency of firms, innovations for competing in larger markets (Melitz & Trefler 2012), could be augmented through the complementary effects of transport. Gains from trade that are foregone to high transport costs that are attributed to low scale effects, as is the case of landlocked countries, or poor infrastructure could be overturned through effective investment policies and/or reallocation of freed-up administrative resources that have resulted from liberalisation itself (Limao & Venables 2001, Winters 2004).

Finally it is deduced that the complementarity of tariff reductions and transport technology needs to be viewed as part of a greater set of adjustments explaining trade growth such as income growth and convergence (Baier & Bergstrand 2001) and vertical specialisation growth (Yi 2003). It thus still remains unclear what is the contribution of transport cost reductions and trade liberalisation in explaining economic progress, paving an avenue for future research.

Chapter 4

Robustness and Contagion in the International Financial Network

This chapter has been co-authored with Tilman Dette MA, Department of Economics, Harvard University, Cambridge, MA 02138 USA, Email: tdette@fas.harvard.edu; Dr. Scott Pauls, Professor of Mathematics, Department of Mathematics, Dartmouth College, Hanover, NH 03755 USA, Email: scott.pauls@dartmouth.edu; Dr. Daniel N. Rockmore, Professor of Mathematics, Department of Mathematics, Dartmouth College, Hanover, NH 03755 USA and The Santa Fe Institute, Santa Fe, NM 87501 USA, Email: rockmore@cs.dartmouth.edu

We highlight the importance of modeling financial networks that represent real world transaction systems relative to abstract artificial topologies. In particular, by employing a variation on so-called "knock-out" experiments, a form of simulation analysis frequently used in the study of various complex networks, we show that the international financial network derived from the IMF Coordinated portfolio investment survey (2013) displays characteristics that are similar to the class of robust-yet-fragile networks: That is, the CPIS network is robust to random country default but fragile if subjected to a targeted default of a highly connected country. Our simulations make use of an adaptation of a commonly used model of contagion. Using this model we run a large collection of default scenarios. The robust-yet-fragile nature of the network is further manifested in the observation that failure of a peripheral country such as Greece can be absorbed by the network in the next round under a range of loss rates, but combinations of peripheral shocks or default of a financial centre increases the likelihood of observing cascades. Over the years 2001–2007, we find a marked rise in frequency and severity of default cascades in the network followed by a decline over the period 2008–2009. Average contagion levels in the network remain low over the same period.

4.1 Introduction

The global financial crises of the early twenty-first century have made clear that the increased interdependencies of national economies as brought about by globalisation and the liberalisation of capital flows may contribute to the propagation of shocks across the global financial system, thereby leading to default cascades, which in turn often require costly governmental interventions (Battiston, Gatti, Gallegati, Greenwald & Stiglitz 2012, Elliott, Golub & Jackson 2013) for their mitigation. At the heart of this transmission mechanism lies the little understood causal link between the network structure of financial interdependencies, that not only enable risk sharing benefits for agents, but also raise the spectre of systemic risk, the risk that the whole system of transactions fails (Lorenz, Battiston & Schweitzer 2009, Cabrales, Gottardi & Vega-Redondo 2013, Caccioli, Farmer, Foti & Rockmore 2013).

Our paper quantifies an aspect of this double-edged sword by bringing to bear simulation tools to a specific network of nation-to-nation financial relationships, as a means of articulating the risk of failure of the international financial system. In this way we add to the body of work that is highlighting the importance for modeling specific networks that characterise real world transaction systems relative to abstract artificial topologies, when examining how structural parameters could amplify or impede contagion channels (Nier, Yang, Yorulmazer & Alentorn 2007, Gai & Kapadia 2010). This kind of work may in turn suggest that incentives designed to safeguard financial stability and reduce systemic risk could be further refined by assimilating the inherent resilience of the underlying network architecture (Elliott, Golub & Jackson 2013).

In particular, we employ data on nation-to-nation financial exposures represented by the IMF Coordinated portfolio investment survey (2013) to construct a network representing international financial dependence. We make use of a family of null models (ensembles of networks that share aggregate various statistics of the given empirical network) to study the stability of the CPIS network when subjected to shocks, represented by various forms of default scenarios. Generally, we find that the CPIS network can be classified as robust with respect to the default of a random country but fragile in the face of default of a highly connected country. The consequence is that the spread of losses across the system following the default of a less connected or peripheral country can be absorbed by the network in a short time frame, but various combinations of peripheral shocks or default of a highly connected node – a financial centre – raises the the likelihood of observing default cascades of significant intensity.

The network's *robust-yet-fragile* behaviour relative to these kinds of shocks is measured in terms of the degree of degradation in network connectivity after removal of nodes and is quantified via a network statistic such as the average shortest path length (Albert, Jeong & Barabási 2000, Foti, Pauls & Rockmore 2013, Caccioli, Farmer, Foti & Rockmore 2013). While this methodology has been applied in a variety of contexts,[1] to our knowledge it has not been implemented in a financial system of transactions.

The robust-yet-fragile network characterisation is commonly associated with scale-free or small world networks (Newman 2000). However, we do not find the CPIS networks (over the years 2001–2009) to share these properties, implying that they are part of a new kind of robust-yet-fragile class.

This result is supported by the outcomes of related studies on empirical financial networks. Boss, Elsinger, Summer & Thurner (2004) provide evidence that the Austrian interbank market exhibits degree distributions that follow a power law, while Caccioli, Farmer, Foti & Rockmore (2013) and Soramäki, Bech, Arnold, Glass & Beyeler (2007) show that for the same network and its US counterpart respectively, these distributions adhere roughly to power laws only in an interval of asset values. The German interbank network considered in Craig & von Peter (2010), displays behaviour similar to a scale free network due to its tiered structure, yet the authors reject the null of a theoretical representation by a scale free network.

Our findings are derived by utilising two key dimensions of the data. Based on Elliott, Golub & Jackson (2013) we adopt the concepts of diversification and integration, pertaining accordingly to how spread out are the cross-border holdings of each country in the network and the total value of a country's cross-border holdings of another country's assets. Controlling for integration levels, diversification is used to deduce the robust-yet-fragile tendency of the network. Integration is invoked to yield the potential for contagion given the annual diversification levels in the network.

Shocks to the network are propagated according to a dynamic contagion described in Furfine (2003) and Upper (2007) wherein a threshold on the size of its asset portfolio and national income is used to assess whether a country's losses from exposure to the set of defaulted partners can be absorbed. Conducting these experiments for each year in our data (2001–2009) reveals a rise in fragility across 2001–2007, reflected in an increase in the severity of contagion and ensuing default cascades, followed by a decline in the next two years. We also find that average contagion levels in the network are low over the same period. Such results are attributed to the robust-yet-fragile tendency of the network implying that the likelihood of contagion is low and is affected by the location of the shock. As an example, a default by a relatively small and peripheral country like Greece can be absorbed but a combination of defaults or the failure of a financial centre can have widespread impacts for the global economy.

[1] Prominent examples are the world wide web (Albert, Jeong & Barabási 2000), food webs (Dunne 2006), international trade (Foti, Pauls & Rockmore 2013), protein (Jeong, Mason, Barabási & Oltvai 2001) and email (Newman, Forrest & Balthrop 2002) networks.

Although simple, this model of contagion provides some basic insights on the propagation of shocks arising from network structure that are in line with the most related studies in this area. In particular, our conclusions are in line with those of Elliott, Golub & Jackson (2013), where increases in integration are found to increase the probability and extent of contagion. The more countries are diversified overall, the less likely that systemic risk is found. It is because of the variation observed in the levels of integration and diversification in the network, that central countries, which have sufficient levels of both, are resistant to peripheral shocks; yet they are not resistant to a failure of another core country. We also find that the probability and extent of contagion in response to equal-sized shocks in the network varies with the location of the shock due to the in-degree heterogeneity of the network. This result is substantiated in Gai & Kapadia (2010) who study the impact of defaults in a dynamic network of interbank claims and obligations as institutions respond to shocks, spurring direct and indirect channels of contagion. With regard to the tiered networks[2] in Nier, Yang, Yorulmazer & Alentorn (2007), our analysis also suggests that peripheral shocks generate default cascades of monotonically decreasing intensity when the degree of centrality increases. Since the empirical degree distributions we consider do not change over time profoundly in order to observe changes in centrality, the aforementioned authors' result that shocks in the centre induce non-monotonic default cascades of increasing and then decreasing intensity as the degree of centrality increases, cannot be confirmed empirically.

Our empirical study on network topology and contagion contributes to the literature by enlarging the class of networks describing financial systems to those exhibiting robust-yet-fragile tendencies supporting the views expressed in Haldane (2009). Evidence for such tendencies or the sufficient condition of a tiered structure in these systems are presented in Boss, Elsinger, Summer & Thurner (2004), Upper & Worms (2004), Soramäki, Bech, Arnold, Glass & Beyeler (2007), Craig & von Peter (2010), Puhr, Seliger & Sigmund (2013) and Caccioli, Farmer, Foti & Rockmore (2013) for the banking system while Schweitzer, Fagiolo, Sornette, Vega-Redondo, Vespignani & White (2009) generalise appropriately for economic networks.

The simulations conducted herein solely focus on assessing the impact of topology on contagion and could be enhanced by the introduction of accounting identities and/or strategic interactions of agents.[3] The potential and severity of contagion could then be understood via the influence of structural parameters given the specific topology as in Furfine (2003), Degryse & Nguyen (2004), van Lelyveld & Liedorp (2006), Nier, Yang, Yorulmazer & Alentorn (2007), Gai & Kapadia (2010), Upper (2011)[4], Gouriéroux,

[2]Networks where links are governed by node size and so first tier or head institutions are connected with each other and with second tier institutions but the latter exhibit limited connectivity between them (Nier, Yang, Yorulmazer & Alentorn 2007).

[3]It can thus be perceived that systemic risk arises as a negative externality (Lorenz, Battiston & Schweitzer 2009).

[4]Who also provides a survey on the channels of contagion.

Héam & Monfort (2012), Battiston, Gatti, Gallegati, Greenwald & Stiglitz (2012) and Georg (2013).

Finally we note that our paper considers network effects and abstains from modelling network formation. Concerning network formation models in finance and banking, the literature has advanced since the seminal study of Allen & Gale (2000) on the containment of systemic risk in complete versus incomplete networks, by incorporating a range of artificial networks through which contagion is studied. Representative examples are Leitner (2005), Gale & Kariv (2007), Babus (2006)[5], Cohen-Cole, Patacchini & Zenou (2011). In Acemoglu, Ozdaglar & Tahbaz-Salehi (2013), Cabrales, Gottardi & Vega-Redondo (2013), Elliott, Golub & Jackson (2013), segmentation, variation in shock size, integration and diversification respectively may lead to the formation of robust-yet-fragile networks *inter alia*.

The remainder of this paper is structured as follows. Section 4.2 describes the data and procedures for constructing the international network of financial exposures and null models. Section 4.3 addresses the ability of the network to attenuate the impacts of a defaulting country via the pattern of interconnectedness. Section 4.4 introduces the model of contagion and illustrates the potential for default cascades stemming from defaults of key countries in the network or combinations thereof. Section 4.5 concludes.

4.2 Description and construction of the dataset

We construct the international financial network utilising the IMF Coordinated portfolio investment survey (2013) (CPIS). The Survey reports bilateral annual financial flows aggregated at the country level. Each country reports year end cross-border holdings of portfolio investment[6] assets, valued at market prices. These holdings are recorded in a two dimensional matrix. An entry s_{ij} represents the year end value of portfolio assets held by residents of a country i, the reporter, which have been issued by residents of country j, the partner. We will say that an entry indicates a value of financial exposure of country i for assets purchased by country j. There are at most 73 reporters and 237 partners within a given year.

We consider only holdings of assets in the CPIS that are valued in excess of 500,000 US dollars for the period 2001–2009. We restrict the dataset to reporting countries which also have available GDP data for each year. This results in a subset of between 64 and 73 reporting countries per year. We then further restrict our attention to those countries which are both reporters and asset holders, so that we obtain a square matrix

[5]A comprehensive survey of the application of networks in finance is Allen & Babus (2009).

[6]Portfolio investment is defined as cross-border transactions and positions involving debt or equity securities, other than those included in direct investment or reserve assets (see the notes section of the IMF Coordinated portfolio investment survey (2013)).

of exposures for each year. Diagonal elements are zero i since the CPIS reports only cross-border holdings of assets. Across the 2001–2009 time period, the resulting matrices cover at least 97.4 percent of the total cross-border holdings of assets reported in the CPIS, as shown in Table 4.1. The studied countries are presented in appendix C.1, accompanied by summary statistics of their portfolio investments. GDP data come from both the IMF World Economic Outlook databases (2013) and the World Bank World Development Indicators (2013).

Table 4.1: Data coverage of square matrices per year

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Coverage	98.0%	98.2%	98.4%	98.8%	98.4%	97.9%	97.5%	97.8%	97.4%

Values indicate the percentage of observations in the CPIS that are present in each square matrix per year.

Similarly to Nier, Yang, Yorulmazer & Alentorn (2007) we conceptualise the CPIS as a network of nodes. Each node represents a country and an edge represents a directional exposure between any two nodes. We construct two empirical networks defined by adjacency matrices $\mathbf{A}$ and $\mathbf{B}$. For a given year, an edge in matrix $\mathbf{A}_t$, $t \in \{2001, \ldots, 2009\}$, is defined as

$$(A_t)_{ij} = \begin{cases} 1 & \text{if } s_{ij} > \sum_{k \neq i}^{n} \frac{s_{ik}}{n-1}, \\ 0 & \text{otherwise,} \end{cases}$$

where n is the number of countries, ranging between 64 to 73 depending on the year. Thus $(A_t)_{ij} \neq 0$ if country i is exposed to country j by more than the average exposure observed in the square matrix corresponding to a particular year. An edge in $\mathbf{B}_t$, $t \in \{2001, \ldots, 2009\}$, is defined as

$$(B_t)_{ij} = \begin{cases} 1 & \text{if } \frac{s_{ij}}{Y_i} > \tau, \\ 0 & \text{otherwise} \end{cases}$$

where Y_i is income of country i and $\tau \equiv 0.0417$ is the mean income weighted financial exposure observed in the square matrices across the time period. Matrix $\mathbf{B}$ is intended to augment the analysis on matrix $\mathbf{A}$ by taking into account the variation of income-weighted exposure amongst countries.

Each empirical network is supplemented by five comparison networks, or null models, constructed algorithmically to capture different network structures. The first of five comparison networks is an Erdös-Rényi network $\mathbf{G}^1_\gamma(n, p)$ consisting of n nodes with probability of edge formation between country i and j being $p = \bar{d}/(n-1)$, where $\bar{d}$ is the *average* out-degree[7] of an empirical network $\gamma \in \{\mathbf{A}_t, \mathbf{B}_t\}$.

Comparison network $\mathbf{G}^2_\gamma(n, p_i)$ comprising n nodes, is described by a probability of edge formation depending on country i's empirical out-degree, $p_i = d_i^{out}/(n-1)$. Comparison

[7]The out (in)-degree of a node is its number of outgoing (incoming) edges (Jackson 2008).

network $\mathbf{G}^3_\gamma(n, p_j)$ is formed by n nodes and a probability that depends on the empirical in-degree of country j, $p_j = d^{in}_j/(n-1)$. These networks are constructed by generating a random graph where a node's probability of edge formation is the number of outgoing or incoming edges over the maximum outgoing or incoming edges observed in the empirical network γ.

The fourth comparison network $\mathbf{G}^4_\gamma(n, [in]_i, [out]_i)$ with n nodes, uses a probability of edge formation that jointly depends on the empirical in- and out-degree of country i in the empirical network γ. To generate $\mathbf{G}^4_\gamma(n, [in]_i, [out]_i)$, we implement a rewiring methodology described in Maslov & Sneppen (2002).

The second, third and fourth comparison networks do not follow the Erdös-Rényi model as the probability of edge formation is not equal across nodes. Hence we will state that for these comparison networks there is variation in the probability of edge formation. In this respect our approach extends that of Nier, Yang, Yorulmazer & Alentorn (2007) since the number of nodes and the probability of edge formation are not randomly assigned - we use statistics derived from the empirical networks.

The fifth comparison network is constructed by taking into account the log-normal distribution of portfolio asset values s in the $n \times n$ matrix for each year. We estimate using maximum likelihood the log-linear model

$$\ln(s_{ij}) = \alpha_i + \beta_j + \epsilon_{ij}$$

where α_i and β_j are country fixed effects and the errors ϵ_{ij} are independent and identically distributed (*i.i.d.*) following a normal distribution with zero mean and constant variance. In addition the errors are assumed to be orthogonal to α_i, β_j. This is motivated by the least squares approximation

$$(n-1)\left(\alpha_i + \beta_j\right) \approx \sum_{k \neq i} \ln s_{ik} + \sum_{k \neq j} \ln s_{kj} + \frac{1}{N} \sum_{k \neq l} \ln s_k$$

which explains around 75% of the variance of $\ln s_{ij}$. We also make the semi-parametric assumption that

$$\epsilon_{ij} \sim \mathcal{N}\left(0, f\left(\alpha_i + \beta_j\right)\right),$$

where we estimate f non-parametrically with a Nadaraya-Watson kernel regression on the squared residuals (Nadaraya (1964); Watson (1964)). The additional flexibility on f is crucial since the variance estimates affect the expected arithmetic mean of s_{ij}: An unconditional model would predict asset exposure magnitudes larger for the right end of the distribution. Lastly, we account for the discreteness and the left-censoring of s_{ij}, since s_{ij} is rounded to the nearest million, by simulating *i.i.d.* errors as $v_{ij} \sim \mathcal{U}\left(-0.5, 0.5\right)$ and estimate the model 10,000 times for $\ln |s_{ij} + v_{ij}|$ averaging the results. Obtaining predicted values of α, β and f we are able to construct $\mathbf{G}^5_\gamma$.

4.3 Robustness

Motivated by recent concerns over the implications following the insolvency of South European countries, we ask how robust is the international financial network to a sequence of random or specific defaults. Robustness pertains to the ability of the network structure to attenuate the impacts of a defaulting country via the pattern of interconnectedness of its nodes: Ceteris paribus, if a country's partner exogenously defaults the impact is mitigated when the reporter is highly interconnected. Holding constant the total value of holdings, the burden suffered from exposure is low compared to a less interconnected country exposed to the same default (Allen & Gale (2000); Battiston, Gatti, Gallegati, Greenwald & Stiglitz (2012); Cabrales, Gottardi & Vega-Redondo (2013)). To this end, we conduct simulations that measure and compare the change in interconnectedness following random and non-random defaults in the empirical and null networks. Thus we are able to analyse the robustness of the international financial network that is borne from its structure.

4.3.1 Methodology

We assume that country j's removal from a particular empirical or comparison network is caused by its idiosyncratic default. This default is considered exogenous to the model and can be regarded as the aggregate observable outcome following an unobservable economic shock in the country's interior. It is also assumed that this default is not the consequence of previous rounds of defaults in the network; therefore the model is static and does not require the modelling of contagious effects. This assumption is relaxed in the next section.

Following Albert, Jeong & Barabási (2000) we measure the change in a network statistic that captures interconnectedness, caused by successive removal of nodes. Nodes can be removed either by random or preferential selection (termed an *error* and *attack* respectively). The sequence of attacks is ordered by decreasing node importance, where importance is expressed via a node's sum of in- and out-degrees.

Node removals alter a network's structure which affects its statistics. We measure the change in the average shortest path length statistic -the average distance between all pairs- as a function of errors or attacks via the following channel of causation: The average path length depends on the degree distribution of a network (Jackson 2008) and the latter is governed by the variation in the probability of edge formation (Albert, Jeong & Barabási 2000). And so one expects to observe different impacts on the average shortest path length depending on the structure of the respective empirical and comparison networks.

The average shortest path length serves in our study as a proxy for the diversification of financial claims in the network. Similarly to Elliott, Golub & Jackson (2013) diversification is defined as how spread out are the cross-border holdings of each country in the network.[8] A low shortest path length indicates high diversification of countries as each is exposed to many others and vice versa. In the aforementioned paper the additional dimension of integration is introduced, referring to the level of exposure of one node to another. In our set-up for identifying robustness the level of exposure, in other words the level of integration, is held constant above the empirical networks' mean thresholds.

Our simulations consist of the following steps.

a. For the *error* part, choose an empirical network $\gamma \in \{\mathbf{A}_t, \mathbf{B}_t\}$:

   i) For a particular year $t \in [2001, \ldots, 2009]$, remove successively 25 nodes at random without replacement. Measure the average shortest path length of the network after each removal. Conduct 2000 independent trials of this process.

   ii) Repeat step i) for all years.

   iii) Calculate the mean and standard deviation of the 2000×9 average shortest path length observations for every node removal.

   iv) Repeat steps i), ii) and iii) for each comparison network $\mathbf{G}^z_\gamma, z \in [1, \ldots, 5]$.

b. For the *attack* part, choose an empirical network $\gamma \in \{\mathbf{A}_t, \mathbf{B}_t\}$:

   i) For a particular year $t \in [2001, \ldots, 2009]$, remove successively the most important 25 nodes by descending order without replacement. Measure the average shortest path length of the network after each removal.

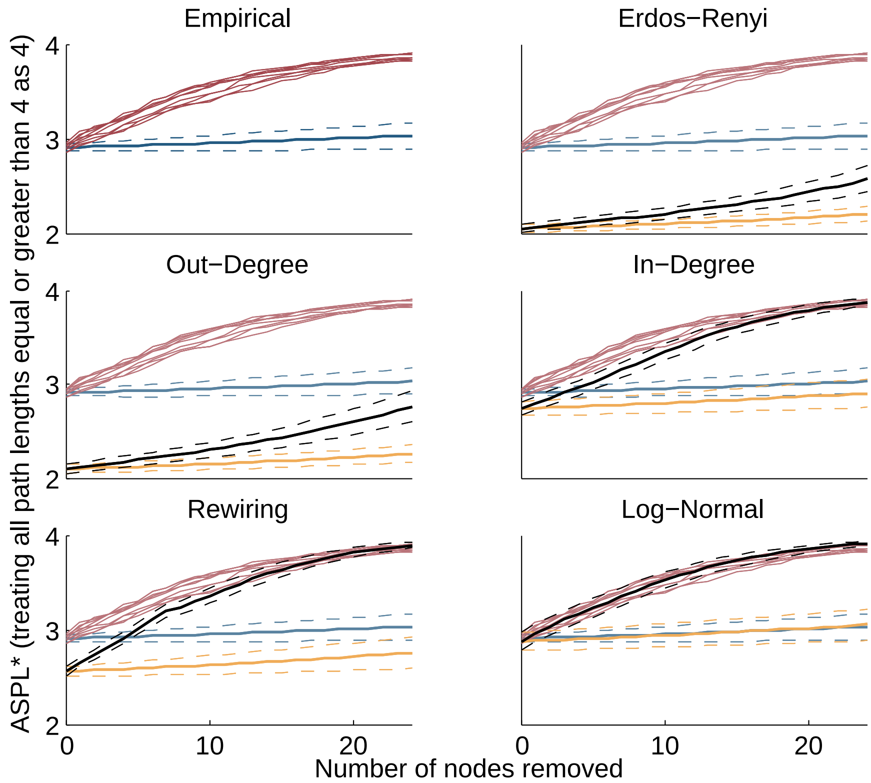
   ii) Repeat step i) for all years.

   iii) Repeat steps i) and ii) for each comparison network $\mathbf{G}^z_\gamma, z \in [1, \ldots, 5]$.

In our simulations as the average shortest path length statistic grows following removals of nodes, its interpretation becomes more adverse. In addition not all pairs of nodes have paths between them. We thus create a modified average shortest path length (mASPL) by placing an upper bound on the shortest path length: We replace observations with path length greater than three as having path length four. We also tracked the evolution of simpler statistics. The fraction of shortest path lengths equal to or less than two yielded qualitatively similar results. Utilising the harmonic mean path length without applying any censoring on the path lengths validated the findings presented below.

[8]Similar notions are described in Allen & Gale (2000), von Peter (2007), Allen & Babus (2009) and Weistroffer & Jochen (2010).

Figure 4.1: Evolution of average shortest path length for empirical networks of the **A** type



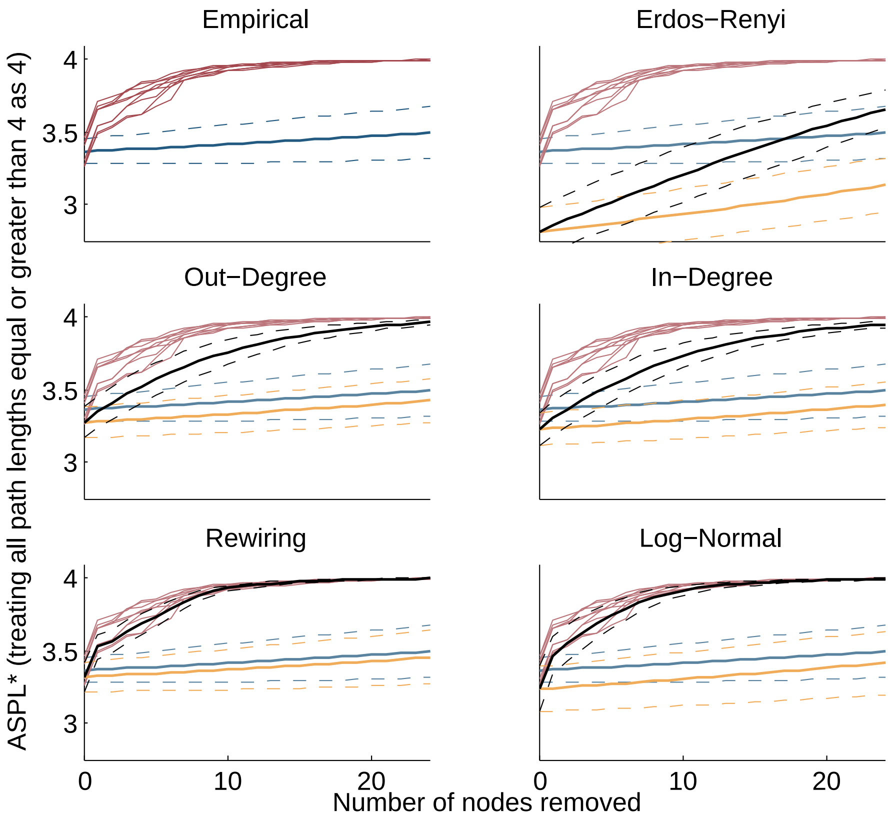
4.3.2 Results

Figures 4.1 and 4.2 exhibit the evolution of the mASPL as a function of errors and attacks. The first panels in both figures correspond to empirical networks **A** and **B** respectively. These depict the mASPL attributed to errors in *blue* by plotting the mean and standard deviation of the 9 years × 2000 independent observations. The mASPL observations caused by attacks are plotted in *red*, where each curve corresponds to a sampled year. Subsequent panels superimpose the mASPL under errors in *yellow* and attacks in *black* for each null model by plotting the mean and standard deviations.

Two main results emerge from our simulations. First the empirical networks exhibit characteristics associated with the robust-yet-fragile class of networks. Second we are able to identify the presence of financial centres in the international financial network due to variation in the sum of in- and out-degrees which determine node importance.

For the sequence of errors we observe across the empirical and comparison networks in Figure 4.1 that the mASPL is monotonically weakly increasing on average. Concerning the Erdös-Rényi model in the second panel, this result is explained by the constant probability of edge formation which is a function of the average out-degree of the empirical network. As nodes have approximately the same out-degree there is equal contribution to the network's mASPL (Albert, Jeong & Barabási 2000). Due to the lack of variation

Figure 4.2: Evolution of average shortest path length for empirical networks of the **B** type



in the probability of edge formation we expect that this result would also hold when we proceed to successive attacks. Preferentially removing nodes by order of importance indeed does not have a significantly more adverse impact than the random removal of a node. Only after removing about 15 percent of the network's nodes the impact becomes significantly more pronounced.

Focusing on the empirical network, errors do not noticeably affect the mASPL. Yet attacks have a starkly different impact. Removing the most important node increases the path length sharply; subsequent attacks increase the path length with an ever decreasing rate implying also variation in importance. This finding can be explained by a tiered organisation of the financial network: Under errors, there is increased probability that a defaulting country is characterised by relatively low connectivity which has little effect on the mASPL. On the contrary when a highly connected country defaults, the implications can be substantial. The financial network becomes increasingly disconnected since the mASPL increases, yet this will occur with low probability unless there is a preferential removal.

The default of an important country due to an attack affects other countries via the direction of exposure. If its importance is driven by its in-degree then most countries in the network are exposed to its default and vice versa. The third and fourth panels of

Figure 4.1 support this case. The empirical network is better approximated by a random graph with variation in the probability of edge formation that is associated with j's in-degree rather than i's out-degree. The implication is that most countries in the network are exposed to an important partner. It then depends on whether these countries are sufficiently diversified and/or less integrated with j in order to mitigate the impact of the latter's potential default. The third panel indicates that the diversification level of the empirical network's majority is low compared to the null model. Therefore the magnitude of the impact following a default depends on the level of integration which we explore in the next section.

We conclude that the international financial network is *robust* in the sense that it exhibits a tolerance against a random default of a country. In expectation this country is one with low diversification of exposures mainly directed to the network's important countries. But it is also *fragile* because of the network's inherent variation in importance which induces the tier structure (Nier, Yang, Yorulmazer & Alentorn 2007). The default of an important country can generate widespread impacts across the network, because of the relatively low diversification of countries in the periphery.

Figure 4.2 further confirms the robust-yet-fragile nature of the international financial network. The empirical network of the first panel depicts error and attack characteristics similar to those of Figure 4.1. The random and preferential removals of nodes in the Erdös-Rényi model of the second panel are significantly different at a much smaller fraction however, at about 7 percent of removed nodes. The remaining null models show results that lie in between the empirical and the Erdös-Rényi counterparts.

The third and fourth panels of Figure 4.1 provided evidence that the degree distribution of the empirical network can be approximated better by the variation in countries' in-degree rather than their out-degree. Regarding the simulation outcomes of Figure 4.2 this result cannot be verified due to the very close performance of the second and third null models which replicate the empirical network reasonably well. These experiments indicate that most countries are exposed to an important partner as is the case with Figure 4.1. In addition, when employing income-weighted exposures, we document that importance is also governed by the out-degree implying that important reporters are exposed to peripheral partner countries. The joint influence of both out- and in-degree variation becomes evident in the fifth panel of Figure 4.2 were the null model replicates the empirical network most accurately.

The characteristics of the two empirical financial networks **A** and **B** as well as the null models that are governed by variation in the probability of edge formation are consistent with those of the broad class of *robust-yet-fragile* networks as detailed by Albert, Jeong & Barabási (2000), Newman (2003) and Doyle, Alderson, Li, Low, Roughan, Shalunov, Tanaka & Willinger (2005). On the contrary, networks which have a constant probability of edge formation do not. While such observations are a typical consequence arising from the underlying scale-free degree distribution of a network, the reverse is not always true (Foti, Pauls & Rockmore 2013). Scale free networks incorporate two key components of self-organisation: growth and preferential attachment. Growth is achieved by new nodes connecting to already existing nodes *because* of the latter's degree of connectivity (Albert, Jeong & Barabási 2000, Wang & Chen 2003). Our experiments abstain from modelling preferential attachments as edges are encoded based on exogenous artificial thresholds of the (weighted) value of exposures. We do not document connectivity distributions that conform to a power law.[9] But a sufficient condition associated with observing a robust-yet-fragile network, the presence of heavy tails in the degree distribution (Caccioli, Farmer, Foti & Rockmore 2013), is upheld. Thus our results introduce a novelty as we are able to classify an empirical non scale-free directed network using error and attack simulations, in the class of robust-yet-fragile networks that are most commonly associated with, but not restricted to, scale-free networks.

A corollary of our findings, similar to Boss, Elsinger, Summer & Thurner (2004), is that we are able to identify the existence of financial centres in the empirical network. A targeted node removal induces higher mASPL's because of the existence of financial centres, otherwise targeted and random removals would have no statistically significant difference unless the fraction of nodes already removed is very large. This is particularly reflected in the fourth panel of Figure 4.1 as the null model with variation in probability of edge formation that depends on the in-degree of country j approximates the behaviour of the empirical network. Hence countries with low diversification are more likely to be exposed to a few partners in the network. These few on the contrary have high diversification of exposure since assets are purchased from similar countries and/or partners with low diversification, which can be justified by the underlying differences in the size and income distributions among countries (Boss, Elsinger, Summer & Thurner 2004).

4.3.3 Discussion

Our approach builds on the empirical section of Gai & Kapadia (2010) who consider only random selection of defaulting banks, corresponding to the *error* part of our methodology. We are also able to deduce the impact on network resilience when highly interconnected countries are removed by descending order.[10] By allowing for variation in the probability of edge formation we are also extending the work of Nier, Yang, Yorulmazer & Alentorn (2007) on the impact of network structure on the likelihood of contagious events. The null networks we examine encompass the random graph and are allowed to

[9] This statement is supported with evidence provided in Appendix C.2.

[10] Their robust-yet-fragile definition of a financial system however, differs to ours as it arises from changes in a bank's in-degree which govern its solvency condition. Subsequently changes in the average degree of the network determine the probability and extent of contagion which is found to be non-monotonic. Thus *a priori* indistinguishable shocks to the network may create varying realisations of contagion.

be inhomogeneous that is, the (minority) majority of nodes have a (large) small number of edges. Craig & von Peter (2010) yield an equivalent outcome to ours, as the German interbank network exhibits a tiered structure which is however formed by a set of core banks acting as intermediaries.[11] Structurally our results coincide since central nodes may transact with other central nodes and/or with peripheral institutions but rarely are peripheral institutions sufficiently diversified. Yet due to the nature of our data we are not in the position to identify whether the observed tiering, and subsequently the robust-yet-fragile behaviour of the network, is induced by intermediation or other factors.

The adherence of the international network of exposures to the tiered network structure neither implies nor motivates a remedial approach of proposing topologically denser, relatively complete networks as a means to diversify systemic risk. The network we document departs from the stylised artificial depictions of complete/incomplete and money centre networks featured in the strand of the literature with representative contributions by Allen & Gale (2000), Leitner (2005) and Gale & Kariv (2007). Craig & von Peter (2010) state that there must be economic reasons behind the self-formation of such real world networks into tiered network structures. They propose amongst others that individual bank balance sheet variables explain the network positioning of banks. Battiston, Gatti, Gallegati, Greenwald & Stiglitz (2012) put forward that the degree of heterogeneity in robustness for financial institutions as measured through their respective equity ratios, results in higher systemic risk with increased connectivity. Schweitzer, Fagiolo, Sornette, Vega-Redondo, Vespignani & White (2009) warn of unpredictable implications following the simultaneous removal of more than one nodes in relatively complete networks.

Our findings motivate an empirical study of financial contagion embedding a robust-yet-fragile network. The aim is to signify the importance of considering the underlying network structure when studying contagion effects rather than adopting *ex ante* homogeneous network structures (Nier, Yang, Yorulmazer & Alentorn 2007) or rigid topologies whose insights may not generalise well as mentioned in Gai & Kapadia (2010) and Upper (2011).

We conclude our identification of robustness in the international financial network by providing formal tests on whether the modified average path length as well as five additional network statistics for the empirical networks behave as outliers within the null model families. For each empirical network $\mathbf{A}$, $\mathbf{B}$ we generated 10,000 networks of the null model $\mathbf{G}^z_\gamma, z \in [1, \ldots, 5]$ across the time period. Then for each $\mathbf{A}$, $\mathbf{B}$ we construct 95% confidence intervals for the mASPL, the fraction of shortest path lengths less than or equal to 2 and 3, network assortativity and the average clustering coefficient. Table 4.2 summarises how often the empirical networks produced measures below (negative)

[11] That is, acting both as a lender and borrower in the interbank market (Craig & von Peter 2010).

Table 4.2: 95% confidence interval for network measures

	Erdös-Rényi		Out-Degree		In-Degree		Rewiring		Log-Normal	
Network Measure	A	B	A	B	A	B	A	B	A	B
Fraction of SP≤2	-1	-1	-1	0	-0.79	-0.33	-1	-0.56	0	-0.11
Fraction of SP≤3	-1	-1	-1	-0.33	-1	-0.78	-1	-0.56	-0.11	-0.67
Modified ASPL	1	1	1	0.33	0.89	0.78	1	0.67	0	0.44
Assortativity	-1	-1	-1	-0.89	1	-0.89	1	0.78	0.11	0
Avg. Clustering Coefficient	1	1	1	1	1	1	1	-0.22	1	0
$\Pr(i \to k \mid i \to j \wedge j \to k)$	1	1	1	1	1	1	1	1	1	1

Fraction of number of years in which the respective empirical network measure was below (negative) or above (positive) the 95% confidence interval for each comparison network. The Modified ASPL indicates the average shortest path length censored at path length four. Assortativity and the average clustering coefficient measures were derived following the Matlab algorithms of the Brain connectivity toolbox (2013).

or above (positive) these confidence intervals. The results support several of our conjectures presented above. We find that the average path length of the empirical network family **B** is indeed best matched using the fourth null model. Yet none of the comparison networks can account for all the listed statistics. Notably and implicitly seeking the presence of intermediation discussed above, the last measure being the probability that country i has a path to k conditional on i having a path to j and j having a path to k is above the confidence intervals of all null models for all years and specifications. Hence the null models' first-order statistics appear unable to account for several relevant characteristics of the empirical network structure.

4.4 Contagion

Our approach so far considered a static environment where, under varying network topologies, nodes were removed randomly or selectively in order to identify the robustness of the international financial network. The analysis focused on measuring the change in the level of diversification of countries holding constant their level of integration above two particular thresholds. In this section we study how the level of exposure of a reporter to a specific partner could trigger a default cascade following the latter's default, by taking each node's diversification pattern as given. Modelling a dynamic interdependence between countries via the level of integration allows us to document the network's robustness to contagion, or contagion potential, following both idiosyncratic and aggregate shocks, given the robust-yet-fragile topology.

4.4.1 Methodology

We adopt the methodology described in Furfine (2003) and Upper (2007) for modelling contagion in the banking system following an initial shock which is propagated by the level of interbank exposures. Our simulations consist of the following steps.

a. A specific country j in the international financial network, or combination thereof, is added exogenously to a set D, which is initially empty. Elements of this set represent countries which have defaulted on their obligations against claims issued by reporter country $i \notin D$.

b. Any country exposed to the failed node will also default if its exposure exceeds some fraction of i) its total exposure to partners and ii) its national income. Formally,

$$\text{Default}_i = \begin{cases} 1 & \text{if } \sum_{j \in D} s_{ij} > LGD_1 \times \sum_{j=1}^{N} s_{ij} \text{ and } \sum_{j \in D} s_{ij} > LGD_2 \times Y_i \\ 0 & \text{otherwise} \end{cases}$$

where $0 \leq LGD_l \leq 1$, $l = \{1, 2\}$, is an exogenous constant inverse loss-given-default,[12] or inverse loss rate (Upper & Worms 2004), reflecting a country's ability to absorb losses relative to its portfolio ($l = 1$) and national income ($l = 2$).

c. The set D is updated to incorporate the identity of defaulted countries and the process repeats from step b until no additional countries fail the threshold.

We then recover the sequence of defaults in each round thus identifying how the pattern of interconnectedness of the network contributes to the default cascade for specific loss-given-default rates.

4.4.2 Results

Our simulations show, using a combination of loss absorbing threshold scenarios, that the network exhibits increased fragility over time with respect to the failure of key countries and combinations thereof. We are able to rank such countries and combinations by their frequency of participation in a worst case default cascade.

Setting both the inverse loss rates to 10% and choosing an initial default of any South European country for year 2007 results in a single default in the next round and the process terminates. However using the same loss rates and assuming the initial aggregate default of Greece and Ireland triggers six rounds of default sequences - a default cascade.

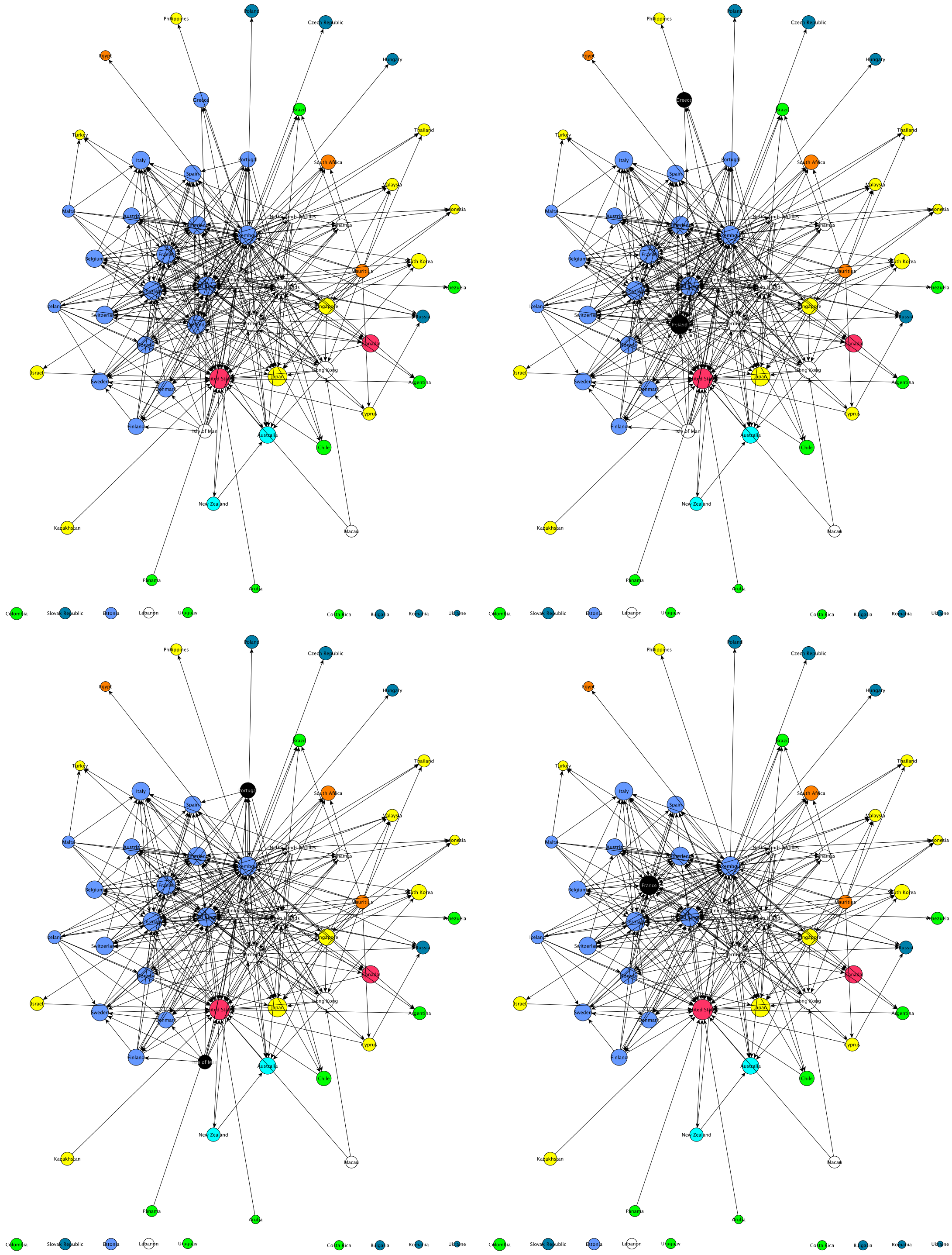
Figure 4.3 exhibits the contagion and ensuing default cascade in the international financial network for this particular example. The eight panels in this figure show the defaulting countries in each round stemming from the initial assumption. The defaulting countries are displayed in *black* before being removed in the subsequent panel. For graphical clarity only edges with asset exposure above 5.81% of the reporter's GDP are displayed in the figure, where 5.81% is average exposure in the network for 2007.

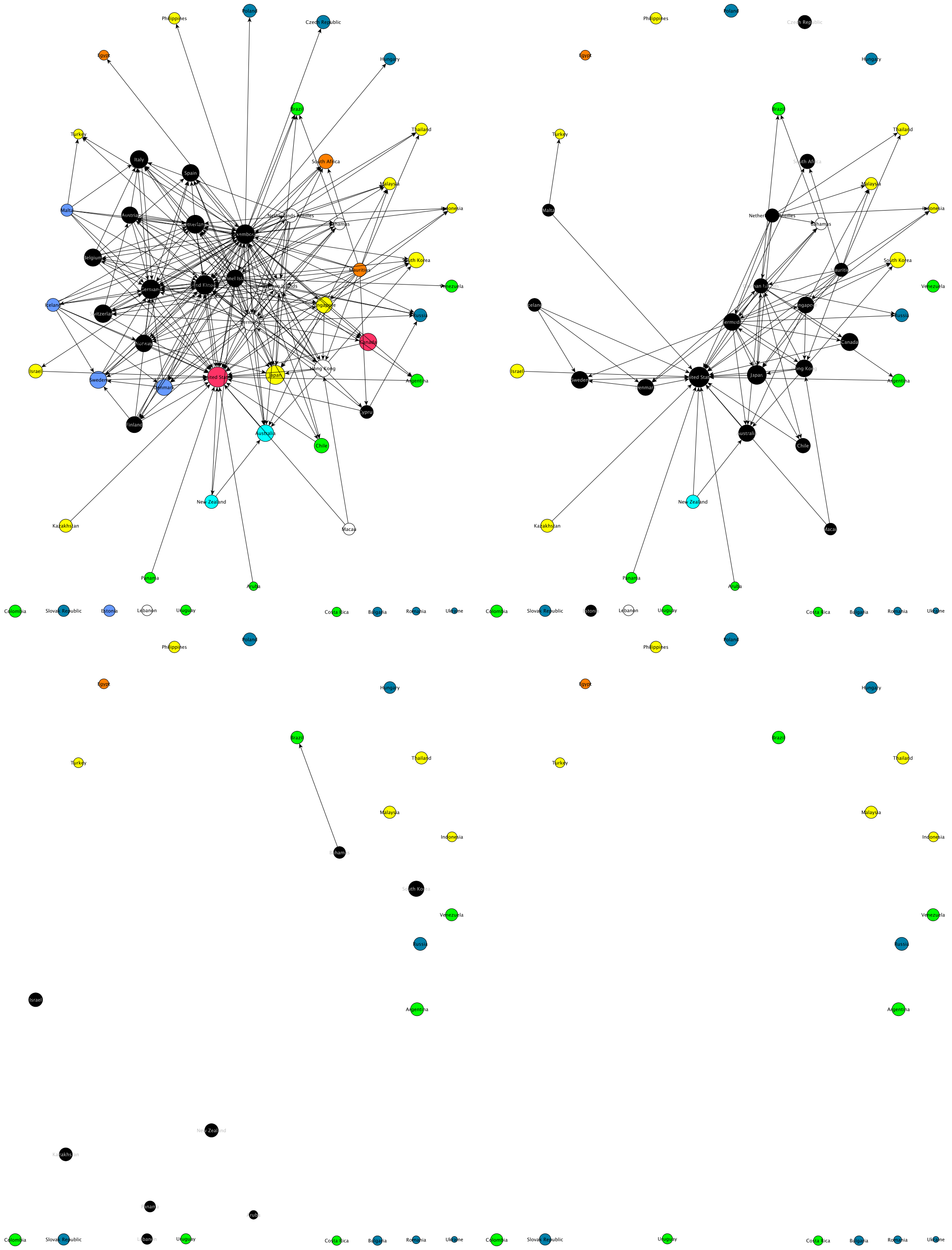
[12] There is some abuse of notation here imposed for clarity.

Western European countries are first affected and therefore default as they fail both thresholds, followed by the United States. Since the in-degree of the latter is high, once the United States are affected, contagion spreads to the rest of the world. In the final round corresponding to the last panel of the figure, one observes only a set of developing countries emerging unscathed from the cascade as their exposure is relatively small relative to their respective GDP. The transition from the fourth to the fifth panel illustrates the consequences of the network's robust-yet-fragile nature. The spread of defaults is initially confined to peripheral countries or territories. Yet once a node having a high degree such as France is reached and fails the threshold then the supported cluster comprising most Western European countries collapses in the next round.

Thus the network proves to be robust to contagion when failures of countries which have relatively low diversification occur in the sense that contagion is contained in the periphery because of the structure. The presence of a cluster of countries which is relatively more diversified increases the likelihood of contagion. If a country in this cluster fails the threshold, the results tend to be severe depending on the size of the cluster itself (Gai & Kapadia 2010).

Figure 4.3: Exogenous default of Greece and Ireland in 2007





Nodes are colour coded by geographical region according to the United Nations composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings (2013).

We run a set of simulations using a range of values for the inverse loss rates and pooling the data across years. We consider all possible model specifications with LGD_1 and $LGD_2 \in \{0, 0.1, 0.25, 0.5, 0.75\}$ whilst we exclude the trivial case of $LGD_1 = LGD_2 = 0$. For each inverse loss rate value and year, all possible combinations of one, two and three countries are examined. We then calculate the mean, the mean of the worst 5% and the worst case default cascades in the international financial network, measured as the fraction of countries that eventually default after each simulation.

Figure 4.4 summarises these findings. Each row of panels corresponds to the number of assumed initial defaults with columns representing the average contagion, the mean of the worst 5% and the worst case defaults respectively. For a given year the vertical axis of each plot indicates the severity of a default cascade, ranked from high to low, as measured by the fraction of countries that default.[13]

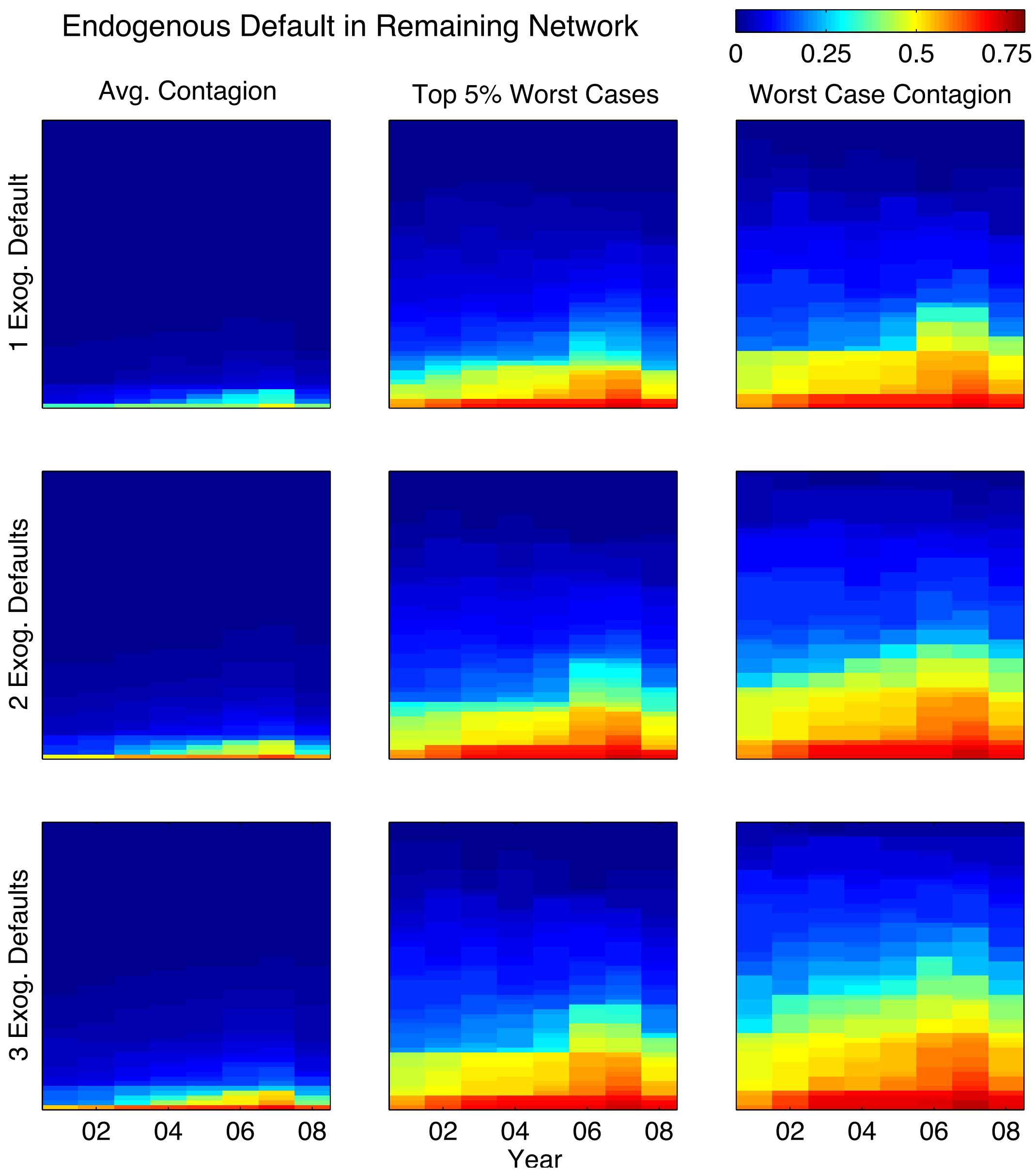
The experiments reveal an increase in fragility, as the severity of worst case default cascades increases from 2001 until 2007. Most notably the combinations of LGD_1 and LGD_2 that produce a worst case default cascade affecting more than 55% of the network doubles in 2006 and 2007. This result could be attributed to the fact that securitisation was reaching its peak during the period (Acharya, Philippon, Richardson & Roubini 2009, Brunnermeier 2009) and by extrapolation diversification and integration levels increased. Not surprisingly, the findings document the subsequent decline in the number and level of exposures following the summer of 2007. We observe lower frequencies of default cascades since the simulations do not account for already incurred losses. Our model is static in its time dimension by not including incurred losses originating from the previous period. Incorporating such losses in the dynamic process provides an interesting extension as the inverse loss rates would be endogenised.

The average contagion level remains very limited in its extent across years pointing to the characteristic robustness of this particular network. Combined with the worst case contagion cases depicted in panels of the second and third columns, our findings suggest that the likelihood of contagion may be indeed low, due to robustness, but with widespread impacts if diversification in the periphery and/or integration levels increase or when a financial centre defaults.

We recover the individual countries and combinations of two and three thereof which participate in the worst case default cascades after each simulation in Table 4.3. The prevalence of the United States, the United Kingdom and Germany are evident due to their increased degree, acting as financial centres. Yet the prominence of the Cayman Islands and Luxembourg as well as IMF classified emerging economies such as Brazil in joint failures with the United States reveal the intricacy of asset transfers offshore[14]

[13]This implies that the loss rates are not constant across the horizontal axis.
[14]We use the IMF Classification of offshore financial centres (2000).

Figure 4.4: Summary of default cascades across years



and the improved net foreign position of emerging economies.[15] The implication is that such countries, given an initial exogenous default of a third country, have the ability to amplify the default cascade due to their relatively high degrees. This takes place within their own cluster of influence which encompasses geographically proximal countries.

[15]See Rose & Spiegel (2007) for a comprehensive study of offshore financial centres and Lane & Milesi-Ferretti (2007) for a treatise on the positions of emerging economies, both employing (but not limited to) the IMF Coordinated portfolio investment survey (2013)

Table 4.3: Top 10 most contagious countries

One Initial Default	Instances	Two Initial Defaults		Instances	Three Initial Defaults			Instances
United States	0.938	United Kingdom	United States	0.523	Germany	United Kingdom	United States	0.347
United Kingdom	0.288	Brazil	United States	0.486	Brazil	United Kingdom	United States	0.309
Cayman Islands	0.276	Germany	United States	0.344	Brazil	Germany	United States	0.283
Germany	0.247	Turkey	United States	0.307	Brazil	Turkey	United States	0.271
Luxembourg	0.247	Indonesia	United States	0.302	France	United Kingdom	United States	0.267
France	0.226	France	United States	0.29	Brazil	Russia	United States	0.266
Brazil	0.214	Russia	United States	0.271	Brazil	Poland	United States	0.257
Italy	0.205	Italy	United States	0.269	Brazil	Indonesia	United States	0.255
Netherlands	0.205	South Korea	United States	0.266	Brazil	Colombia	United States	0.255
Japan	0.2	Australia	United States	0.266	Germany	Italy	United States	0.253

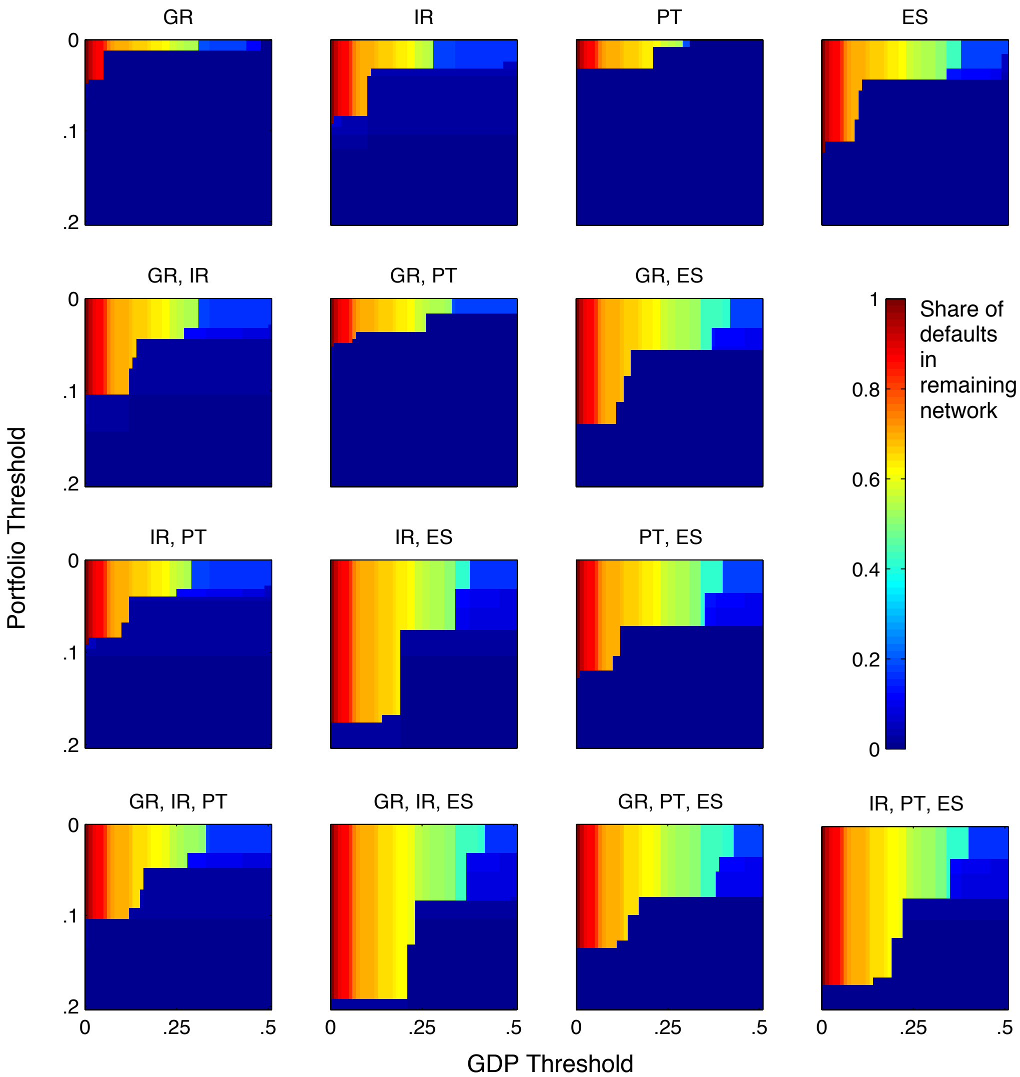
The countries and combinations thereof are ranked by the percentage of times they appeared in the worst cases of contagion in the network amongst the 576 simulation attempts.

4.4.3 Discussion

Our methodology proposes a way of identifying the consequences of a particular pattern of interconnectedness based on a real world complex network. In agreement to Boss, Elsinger, Summer & Thurner (2004), we advocate the use of a more realistic class of networks when modelling interbank or inter-institutional relationships, relying less on abstract structures. Our simulations revealing the contagion potential in a robust-yet-fragile network has yielded meaningful answers concerning the dissipation of shocks, a topic which is assuming centre-stage in policy debate as highlited in Gai & Kapadia (2010) and Haldane (2009). While we did not set out to address specific policy recommendations, a corollary of our results is that proposed incentives designed to safeguard financial stability and reduce systemic risk may be further refined by assimilating the inherent resilience of the underlying network architecture (Elliott, Golub & Jackson 2013).

The systemic risk observed in our results is the macroscopic outcome of a system governed by interactions at the micro-level (Lorenz, Battiston & Schweitzer 2009). In this regard, our experiments may not immediately make clear how the spread of contagion and subsequent default sequences could generalise when modelling an international system of transactions. Intuitively one should expect an amplification or a dampening of the spread depending on the respective model's structural parameters taking the particular network as given, which constitutes an avenue for future research. For example Nier, Yang, Yorulmazer & Alentorn (2007) consider the ceteris paribus impacts of capitalisation, the size of interbank exposures, concentration and connectivity. Martínez-Jaramillo, Pérez, Embriz & Dey (2010) mention that topology is indeed a necessary but not sufficient condition to prove that any system is more robust or fragile as a whole compared to alternatives. It would further depend on the probability distribution of shocks, the size of the losses, the probability of joint failures which define the distribution of losses in the system. Once this distribution is obtained, then one would be able to comment on the specific benefits of particular topologies.

Figure 4.5: Summary of default cascades stemming from Ireland and south European Countries



4.4.4 A Thought Experiment

The recent concerns relayed by media over the solvency of Ireland and the South European countries motivate a restrictive study of the implications following their idiosyncratic or aggregate defaults. Using the 2007 network of exposures we carry out a set of simulations assuming initial defaults of an individual country and combinations of two and three thereof. We set the inverse loss rates to $LGD_1 \in [0, 0.2]$ with increments of 0.004 and $LGD_2 \in [0, 0.5]$ with increments of 0.01.

The heat graph in Figure 4.5 illustrates the results, where each panel corresponds to an initial default permutation. For each panel, the vertical and horizontal axes represent the magnitudes of LGD_1 and LGD_2 respectively. Across loss rates, a default by Spain yields the highest fraction of defaulting countries in the network compared to Ireland, Portugal and Greece which follow in ranking. Ireland and Spain's joint default induces the highest frequency of default cascades among any two combinations whilst we observe an equivalent outcome after the inclusion of Greece. Holding constant LGD_2, there is a unique LGD_1 threshold above which a defaulting cascade affecting over 80 percent of countries in the network is generally the norm. Controlling LGD_1, our findings show a graduated behaviour in terms of number of defaults, steadily decreasing as the threshold increases.

4.5 Conclusion

Our paper contributes to the identification of repercussions stemming from defaults in a particular network topology in two ways.

We first show that the international network of financial exposures aggregated at the country level exhibits a robust-yet-fragile tendency, a natural occurrence arising in many real world complex networks. This is achieved by comparing the empirical network with a set of comparison networks each modelled assuming a specific probability of link formation. All networks are subjected to the (non) random removals of nodes without replacement in each network. Robustness is observed in the event of a random default and fragility following the non-random default of countries, because of the underlying variation in diversification, which tends to be low on average. Consequently, the existence of financial centres in the network is confirmed. We do not find evidence that the robust-yet-fragile classification of the financial network arises because the network is scale free, expanding the types of networks that can be admitted to such a class. Our findings motivate, in accordance with Boss, Elsinger, Summer & Thurner (2004), a reduction in the size of candidate networks for theoretical modelling of interbank or financial interdependencies in the presence of other structural parameters.

Second, we investigate the spread of contagious defaults given the robust-yet-fragile empirical network, using the level of integration of countries. Constructing default scenarios that are motivated by the recent sovereign debt crises of South European countries and Ireland, our simulations document a mitigated impact isolated in the periphery. If a highly connected country fails the exogenous exposure threshold, the cluster it supports defaults in the next round. Models that assume low thresholds for the spread of contagion predict that default of a combination of South European countries may be similarly severe. Importantly we find that from 2001 until the eve of the financial crisis the fragility of the empirical network increased as there is a wider range of thresholds that result in a worst case default cascade, but decreased from 2008 onwards. Throughout the period average contagion levels remain low indicating the network's robustness.

The different analytical tools all highlight the key importance of the United States and the centrality of European countries. The only countries relatively unaffected by such global financial crises seem to be middle income countries, whose external financial assets are relatively small as a share of their GDP. A more refined understanding of these results and the further study of systemic risk in the global economy could be achieved by modelling a system of transactions and endogenising the particular network structure. We leave this as a suggestion for future advances in the area.

Chapter 5

Conclusion

This Thesis contributes to the international trade literature by merging the body of work concerning transport costs with that of general equilibrium models of trade in order to identify the causal effects behind two empirically observed phenomena.

First, what are the reasons underpinning transport hub formations in international trade? It is deduced that a trade off between increasing marginal and decreasing fixed costs -implying the existence of increasing returns to scale in transportation- together with geographical centrality of particular areas are sufficient determinants for a hub port to emerge. Therefore concentration of production, created by historical incidence, although reinforces the hub effect, is not found to be a primary determinant thus explaining why some less developed regions of the world obtain hub status. The theory is confirmed empirically by innovatively introducing an origin-destination travelled distance variable which is interacted with a hub area variable and benchmarked against the classic measure of exogenous trade costs, great circle distance. It is found that the former has a lower marginal effect than the latter.

Second, it is asked whether the enormous trade growth is commensurate with only a small (11 per cent) decrease in tariffs over the period. Taking into consideration the prevailing views documented in the literature, it is proposed that there exists a complementarity between trade liberating policies and shipping prices due to the introduction of transport technology. The increased range and quantity of goods transported because of a decline in an artificial barrier, reduce the shipping price to the destination. Yet this reduction might be alleviated by increasing markups or insurance/packaging costs that affect in the opposite way the shipping price, reconciling the theory with the published facts on the non-reduction of shipping prices over the previous 5 decades. Empirical evidence provided herein supports the proposition.

In a distinct chapter, a simulation engine is developed to infer the topology of the international network of financial exposures at the country level. Uniquely, the robust-yet-fragile classification of the financial network does not arise because the network is scale free, broadening the types of networks that can be admitted to this classification. Given the structure, it is illustrated how defaults of peripheral countries can create contagion events that are contained in the periphery of the network but failure of a financial centre can amplify the spread of contagion in the network. Such findings warrant a more realistic representation of real world networks relative to abstract artificial topologies in order to examine the impact of structural parameters such as capitalisation, concentration, the size of interbank exposures and associated losses in propagating financial contagion. A way forward becomes the embedding of such parameters that determine the default of a financial institution in a robust-yet-fragile network in order to infer their individual contribution to contagion cascades in the presence of an inherent resilience to contagion emanating from the network itself.

Promising avenues for future research that stem from the findings and conclusions of the Thesis, are concerned with a structural representation of transport costs in models of international trade either in a multiplicative or additive formulation. Specifically Hendricks, Piccione & Tan (1995) document how economies of density form as marginal costs of transport decline in the volume of passengers travelling on a route which could also be hypothesised, after empirical corroboration, for the carriage of goods. Additional analysis is required to be conducted on the functional form of a hub indicator and its correlation with the level of marginal and fixed costs of transport, where data paucity becomes the primary hurdle.

The proposition of complementarity between tariff and shipping price reductions leads naturally to a re-examination of the contribution of determinants that explain trade growth. Baier & Bergstrand (2001) do not consider adjustments in transportation technology or correlation between shipping prices with tariffs, reporting that the former has had small impact on the growth of world trade, relative to other determinants including tariff reductions. Endogenising the proposed complementarity in their model could yield alternative observations on the contribution of trade growth determinants which could then support the views of Bernhofen, El-Sahli & Kneller (2013) who attribute a very large portion of trade growth to adjustments in transport technology.

Appendix A

A.1 Proof of efficiency and pairwise stability of network formations

A.1.1 Efficiency

Based on the definitions of Jackson & Wolinsky (1996), each graph g has a value $y : \{g|g \subset g^N\} \to \mathbb{R}$, where $y \in Y$ is the set of functions. The value is an aggregate of individual exporting firm values $y_j(g) = \sum_{i:ij \in g} v_{ij}(g)$, where $v_{ij} : \{g|g \subset g^N\} \to \mathbb{R}$ is a net benefit value. The graph $g \subset g^N$ is *efficient* if $y_j(g) \geq y_j(g')$ for all $g' \subset g^N$.

Case 1, Direct Trading vs Autarky: $G = \{g_{ij} = \{12, 21\}, g'_{ij} = \{\emptyset\}\}$— The simplest case shows how forming a direct link is more efficient than not forming a link. Firm profits and utility increases as long as the benefit of forming a link exceeds its cost for countries 1 and 2. Due to symmetry, global utility and firm profits (until the trade equilibrium restores profits to zero) increase:

$$y_1(g) = (\delta - c_{12}) = (\delta - c_{21}) > 0, \text{when } \delta > c_{ij}$$

Case 2, Direct Trading vs Indirect Trading: $G = \{g_{ij} = \{12, 21, 13, 31, 23, 32\}, g'_{ij} = \{13, 31, 23, 32\}\}$— In the case of the direct links network with three countries trading, direct connections are more efficient than indirect connections and no trading at all. Denote the graphs originating from direct trading between any integer pair $\{i, j\} \in [1, 3]$ as g^D. For pairs that are indirectly trading denote their graph as g^I. Therefore in case (i) of the Proposition, country 1 obtains from trading to 2 and 3:

$$y_1(g^D) = (\delta - c_{13}) + (\delta - c_{12}) > \delta - c_{13} + \delta^2 = y_1(g^I)$$

Country 3 similarly yields:

$$y_3(g^D) = (\delta - c_{31}) + (\delta - c_{32}) = (\delta - c_{31}) + (\delta - c_{32}) = y_3(g^I)$$

because in the two alternate formations country 3, being in the middle, must always form direct connections. The symmetric case for country 1 applies for country 2.

Hence, total profits (or utilities in the receiving countries) have increased by
$y = 6(\delta - c) > 0$.

Case 3: Indirect Trading vs Direct trading: $G = \{g_{ij} = \{13, 31, 23, 32\}, g'_{ij} = \{12, 21, 13, 31, 23, 32\}\}$— Countries 1 and 2 are symmetric, therefore the following is obtained also for country 2.

$$y_1(g^I) = (\delta^2 + \delta - c_{13}) > (\delta - c_{13}) + (\delta - c_{12}) = y_1(g^D)$$

For country 3:

$$y_3(g^D) = (\delta - c_{31}) + (\delta - c_{32}) = (\delta - c_{31}) + (\delta - c_{32}) = y_3(g^I)$$

Hence, total profits (or utilities in the receiving countries) have increased by $y = 2\delta^2 + 4(\delta - c) > 0$.

A.1.2 Pairwise stability

There exists an allocation rule $K : \{g|g \subset g^N\} \times Y \to \mathbb{R}^{\mathbb{N}}$ and $K_j(g, y_j)$ is the distribution of each network value to individual firms or representative agents. The graph is pairwise stable w.r.t. y and K if:

a. For all $ij \in g, K_j(g, y_j) \geq K_j(g - ij, y_j)$ and $K_i(g, y_i) \geq K_i(g - ij, y_i)$.

b. For all $ij \notin g, K_j(g, y_j) < K_j(g + ij, y_j)$ then $K_i(g, y_i) > K_i(g + ij, y_i)$.

The implication is that if j strictly prefers to form link ij and i is indifferent, the link is formed.

Case 1, Direct Trading $c < \delta - \delta^2$***:*** —

a. For $\{ij\} \in [1, 3]$: If any one link is severed, utility (profits) decrease for the trading pair: $\delta - c_{ij} > 0$ as long as $\delta > c_{ij}$.

b. For $\{ij\}$, $i, j \in \{1, 3\}$ and country 2 remaining autarkic: utility (profits) of 2 connecting to 1 or 3 are lowered: $\delta - c_{2j} < 0$. But if $\delta - c_{2j} > 0$, then utility (profits) increase and all links are formed.

Case 2, Indirect Trading $\delta - \delta^2 < c$*:* —

a. For $\{ij\} \in [1, 3]$: If any one link is severed, utility (profits) decrease for the trading pair: $\delta^2 + \delta - c_{ij} > \delta - c_{ij} > 0$ for countries, 1 and 2. For country 3 connected to 1 and 2, $2(\delta - c_{3j}) > (\delta - c_{3j}) > 0$ as long as $\delta > c_{3j}$.

b. For $\{ij\}$, $i, j \in \{1, 3\}$ trading directly and country 2 trading directly to 3. It considers connecting directly or indirectly to 1. Utility (profits) of 2 connecting directly to 1 are lowered: $2(\delta - c_{2j}) < 0 < (\delta - c_{23}) + \delta^2$. But if it actually connected to 1 directly, country 1 has utility (profits) decreased: $2(\delta - c_{1j}) < 0 < (\delta - c_{12}) + \delta^2$ and therefore country 1 will break the link to country 3 and start trading indirectly.

It is deduced that when costs are low, $c < \delta - \delta^2$, the direct links network is uniquely efficient and pairwise stable. When costs are consistent with the range $\delta - \delta^2 < c$, the indirect links network is uniquely efficient. It is also pairwise stable but not necessarily unique as the system can rotate between partners.

A.2 A model of increasing returns to scale in transportation and hub formations

A three country model with increasing returns in each country's transportation sector is constructed in order to prove the existence of a trade off between an increase in distance due to indirect trading and the necessary reduction of fixed costs associated with transportation when the transport sector operates under increasing returns. This theoretical finding has qualitatively the same effects as the theoretical exposition of the paper and yields the same conclusions that lead to the empirical prediction.

A.2.1 Theoretical Framework

The model opens directly in costly trade. Instead of a network, it will suffice to consider a set of countries $K = \{1, 2, 3\}$ that exist in a world where there is symmetry to and from country 3 and an asymmetry between countries 1 and 2. Country 3 shall be in the middle in order to be consistent with the main theoretical model. The asymmetry is measured in terms of distance and therefore: $d_{13} = d_{23} = d < d_{12} = d'$.

All countries are identical technologically and in size. The latter assumption is imposed as in Krugman (1993) in order to set aside the home market effect. An arbitrary country has population L and three sectors, Agriculture, Manufacturing and Transport. The agricultural good is homogeneous and produced under constant returns that will be defined as a numeraire good. The manufacturing good is produced under monopolistic competition and some quantity of the good produced is exported to the other two countries using domestically produced transport services. Transport services are produced under monopolistic competition and are utilised solely for transporting the exporting volume to the importer. As in Krugman (1993) we can allow for mobility of labour between the constant returns and increasing returns sectors but need to impose a fixed labour share in transportation. As such labour is exhausted in employment in the three sectors.

Demand: — Agents in country $i \in K$ notwithstanding their sector of occupation, consume differentiated varieties of agricultural and manufacturing goods under the same utility function,

$$U = q_0^{1-\mu} \left[\int_{\omega \in \Omega} q_{ij}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}\mu}$$

where q_0 is consumption of the aggregate agricultural, $1-\mu$ is the share of income expenditure on 0, $\sigma > 1$ is the elasticity of substitution between pairs of varieties ω and Ω is the mass of available goods. Maximising utility subject to exhausting her labour income share, the representative consumer in country j has demand for differentiated goods:

$$q_{ij} = \frac{\mu L_j p_{ij}^{-\sigma}}{\sum_{j,i=1}^{N} \int_{\Omega} p_{ij}^{1-\sigma}(\omega) d\omega}, j \in K$$

It will be notationally convenient to define $\theta = \frac{\sigma-1}{\sigma}$, $0 < \theta < 1$ as the intensity of the preference and when θ approaches 1 varieties become almost perfect substitutes. As θ approaches zero an increased number of varieties results in higher utilities.

The demand function can then be rewritten as $q_{ij} = \frac{\mu L_j p_{ij}^{\frac{1}{\theta-1}}}{P}, j \in K$, where P will represent the price index.

Manufacturing Production and Trade Costs — Good 0, the agricultural good, is the numeraire homogeneous good. One unit of labour produces w and the price of the numeraire is normalised to 1. The wage rate is then equal to the price of the good. In this respect the wage rate is equal to 1 across countries due to free trade, and across the three sectors within each country.

One manufacturing firm can produce one variety of the differentiated good using labour and transportation as an intermediate input only for exporting. Labour costs for differentiated goods are split between a marginal and a fixed cost and thus the sector is characterised by increasing returns.

To produce and sell a variety ω either domestically or abroad, the firm in country i employs labour input:

$$L^m(q) = \gamma q_{ij} + F_i, \quad j \in K, \gamma, F_i^m > 0$$

There is full employment in manufacturing so that the sum of labour used in manufacturing production constitutes the labour share in manufacturing. Lastly all firms must produce goods that are consumed domestically and abroad after exporting.

Pricing Regime: — *cif* prices of imported goods consist of a multiplicative iceberg cost $\tau_{ij} \geq 1$ and an additive transport price f_{ij} that is the optimal price set by the transportation firm (Hummels & Skiba 2004, Irarrazabal et al. 2014):

$$p_{ij}^{cif} = p_{ij}^{fob}\tau_{ij} + f_{ij} \tag{A.1}$$

Transportation Production: — Equivalently to manufacturing, the transport sector produces a continuum of differentiated transport varieties that are used as an intermediate input in manufacturing in order to facilitate exports. One transport variety is utilised to transport the output of one exporting variety[1]. Each country uses transport services produced domestically. Each specific variety is produced by a single transportation firm using labour as its input. All firms have the same cost function, can freely enter or exit production and each worker is endowed with one unit of labour. The production function is

$$L^t(q) = d_{ij}q_{ij} + F_i^t, \qquad i \neq j, d, F_i^t > 0$$

where $F_i^t > 0$ is a variable overhead/fixed cost, $d_{ij} > 0$ is a constant marginal cost of transport production that will be associated with distance to the trading partners. q_{ij} denotes the quantity of output that each transport firm can carry and comprises the quantity produced by one manufacturing firm.

A.2.2 Partial equilibrium in manufacturing

Manufacturing firms in country i maximise profits subject to feasible output. Provided $i \neq j \in K$, their profit function is defined as

$$\Pi_i^m = p_{ii}^{fob}q_{ii} + \sum_{i,j=1}^{3} p_{ij}^{cif}q_{ij} - w\gamma q_{ii} - \sum_{i,j=1}^{3} w\gamma\tau_{ij}q_{ij} - \sum_{i,j=1}^{3} f_{ij}q_{ij} - wF_i^m$$

where the transport revenue obtained from exporting to country j is passed directly to the transport firm. Maximising profits subject to the demand for a domestic good, the profit maximising price becomes $\frac{p_{fob}}{w} = \frac{\gamma}{\theta}$ as marginal revenues (MR) equal marginal costs (MC). Free entry and exit of firms results in zero long term profits for each manufacturing firm and fulfills the equality between price (P) and average cost (AC), $\frac{p_{fob}}{w} = \gamma + \frac{F_i^m}{x_i}$, where x_i is the total output produced by each firm.

[1]This assumption could be too strong. I have shown elsewhere, but omit to prove herein, that if one permits homogeneity of degree greater or less than 1, then transport services can be used to carry more than or less than the exporting output produced by one manufacturing firm. Nevertheless the qualitative results would remain unchanged. This proof can be provided upon request.

Equilibrium is achieved when simultaneously marginal revenue equals marginal cost and price equals average cost. The equilibrium manufacturing output is constant amounting to:

$$x_i = \sum_{i,j=1}^{3} q_{ij} t_{ij} = \frac{F_i^m}{\gamma} \frac{\theta}{1-\theta} \tag{A.2}$$

The number of firms can then be derived due to full employment in the manufacturing sector:

$$n_i^m = \frac{L_i^m}{F_i^m}(1-\theta)$$

A.2.3 Partial equilibrium in transportation

Transport firms, simultaneously to manufacturing firms, maximise profits subject to feasible export output produced by manufacturing firms. They obtain their revenue through the *cif* price of the manufacturing good and the intermediate input assumption. Provided $i \neq j \in K$, their profit function is

$$\Pi_i^t = \sum_{i,j=1}^{3} f_{ij} q_{ij} - \sum_{i,j=1}^{3} w d_{ij} q_{ij} - w F_i^t$$

It is required to assume simultaneous pricing and output determining behaviours of manufacturing and transport firms. Equivalently the manufacturing firm would observe the equilibrium value of f as both entities play simultaneously and have no reason to deviate from their optimal decisions, since labour shares are fixed and the wage is equalised across sectors.

Given this assumption, transport firms proceed to profit maximisation and yield transport prices that are a function of the fob price and a markup over transport marginal cost due to the transport elasticity of import demand:[2]

$$\frac{f_{ij}}{w} = \frac{d_{ij}}{\theta} + \frac{\gamma \tau_{ij}}{\theta} \frac{1-\theta}{\theta}$$

Free entry and exit of firms result in zero long term profits. However the imposed asymmetry between countries 1 and 2 will prevent the export shares being equal for all countries in K. Crucially this fact may give rise to a hub formation.

The characterisation of the transport price allows us then to characterise the *cif* price, reminding that $w = 1$ for all countries:

$$p_{ij}^{cif} = \frac{1}{\theta}(p_{ii}^{fob} \tau_{ij} + d_{ij}) = \frac{1}{\theta}(\frac{\gamma}{\theta} \tau_{ij} + d_{ij})$$

[2] $\epsilon_f = -\frac{\partial q_{ij}}{\partial f_{ij}} \frac{f_{ij}}{q_{ij}} = \sigma \frac{f_{ij}}{p_{ii}^{fob} \tau_{ij} + f_{ij}}$

A.2.4 Hub formations driven by the zero profit condition in transportation

Consumption Ratios: — It will be useful at this point to define consumption ratios as viewed by the exporting firm in order to express exports across all countries in common units. Define hence the ratio of consumption for exports to country j relative to domestic consumption (which is identical in all countries due to similar technology):

$$\frac{q_{ij}}{q_{ii}} = \left(\frac{p_{ij}^{cif}}{p_{ii}^{fob}}\right)^{\frac{1}{\theta-1}}$$

For simplicity let us assume that other trade costs $\tau_{ij} = \tau$ are symmetric and the distortion is only created by the asymmetry $d_{13} = d_{23} = d < d_{12} = d'$. Consumption ratios that exporting firms of country 3 have to face are:

$$\frac{q_{31}}{q_{33}} = \frac{q_{32}}{q_{33}} = \left(\frac{\frac{\gamma}{\theta}\tau + d}{\gamma}\right)^{\frac{1}{\theta-1}}$$

For countries 1 and 2 equivalently we have for trading between them:

$$\frac{q_{12}}{q_{11}} = \frac{q_{21}}{q_{22}} = \left(\frac{\frac{\gamma}{\theta}\tau + d'}{\gamma}\right)^{\frac{1}{\theta-1}}$$

and for trading with country 3 being the most proximal to both:

$$\frac{q_{13}}{q_{11}} = \frac{q_{23}}{q_{22}} = \left(\frac{\frac{\gamma}{\theta}\tau + d}{\gamma}\right)^{\frac{1}{\theta-1}}$$

Prior to deriving the result, let us make one last normalisation since the symmetry of the iceberg trade cost τ and the common marginal cost γ are identical across countries. Hence, impose $\tau = \gamma = 1$.

Country 3, Zero Profit Condition in transportation: — Free entry and exit of transport firms results in zero long term profits satisfying the P=AC condition:

$$f_{31} = f_{32} = d + F_3^t(q_{31} + q_{32})^{-1} \Longrightarrow q_{31} = \frac{1}{2}\frac{F_3^t}{\frac{1}{\theta} + d}\frac{\theta}{1-\theta} \tag{A.3}$$

It is straightforward to see that due to symmetry, the total exports of country 3 are split equally between countries 1 and 2.

Country 1, Zero Profit Condition in transportation: — Free entry and exit of transport firms results in zero long term profits:

$$f_{12}q_{12} + f_{13}q_{13} = d'q_{12} + dq_{13} + F_1^t$$

Using the consumption ratios we can express q_{12} in units of q_{13} and replacing the transport price. The relationship can be rearranged to write:

$$q_{13} = q_{31} = \frac{F_1^t}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}} \frac{\theta}{1-\theta} \tag{A.4}$$

Exports from country 1 (and 2 by symmetry) are clearly less than what country 3 can achieve due to its beneficial location.

Hub formations: — The left hand sides of equations (A.3) and (A.4) are necessarily the same as it is the expression of the common unit of exports. We have assumed that the overhead costs of transportation F_i^t in any country can be variable. Equating the two terms then yields a ratio of the fixed cost of transport in the two countries:

$$\frac{F_3^t}{F_1^t} = \frac{2\left(\frac{1}{\theta} + d\right)}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}} \tag{A.5}$$

The ratio of fixed costs of transport and the assumption of their variability are crucial in identifying the type of formation between the trading countries. The term is increasing in d' since $\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} > 0$. It is decreasing in d since $\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d} < 0$.

Proof. Expression (A.5) has $\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} > 0$:

$$\begin{aligned}
\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} &= -\frac{\left[2\left(\frac{1}{\theta} + d\right)\right] \frac{\theta}{\theta-1} \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}-1} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}}{\left[\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}\right]^2} \iff \\
\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} &= \frac{F_3^t}{F_1^t} \frac{\frac{\theta}{1-\theta} \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}-1} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}} > 0
\end{aligned} \tag{A.6}$$

Since both fractions are positive. (A.5) has also $\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d} < 0$:

$$\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d} = \frac{2}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}}$$

$$- \frac{\left[2\left(\frac{1}{\theta} + d\right)\right]\left(1 + \frac{1}{1-\theta}\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}-1}\left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}\right)}{\left[\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}\right]^2} \Longleftrightarrow$$

multiplying and dividing the first term with $\left(\frac{1}{\theta} + d\right)$ yields (A.7)

$$\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d} = \frac{F_3^t}{F_1^t}\left[\left(\frac{1}{\theta} + d\right)^{-1} - \frac{\left(1 + \frac{1}{1-\theta}\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}-1}\left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}\right)}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}}\right] \Longleftrightarrow$$

$$\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d} = \frac{F_3^t}{F_1^t}\left(\frac{1}{\theta} + d\right)^{-1}\left[1 - \frac{\left(\frac{1}{\theta} + d + \frac{1}{1-\theta}\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}\left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}\right)}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}\left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}}\right] < 0$$

The nominator of the second fraction in brackets is greater than the denominator since products are scaled by $\frac{1}{1-\theta} > 1$ hence the term in brackets is negative. □

These properties allow the following statements:

1. *If country 1 decides to trade using country 3 as a hub, it will have to increase its trading distance to $d'' = 2d > d'$. This will necessitate an increase in the ratio of the fixed costs of transportation between the hub country 3 and country 1. Hence there will either need to be an increase in the fixed costs of transport of the hub country or a decrease in the fixed costs of transport for the connecting country or any increasing combination of both.*
2. *If country 3, the hub country, is ever more distant from the connecting country 1, the ratio of fixed costs needs to be decreased. This implies either a decrease in the fixed costs of the hub country or an increase in the fixed costs of the connecting country or any decreasing combination of both.*

A change in country 1's trading decisions will however not enforce a change in country 3's level of fixed costs as the profit functions of transport firms are independent of each other. Hence all the changes in the ratio are driven by adjustments in the fixed costs of transportation for the connecting country 1. By symmetry of the distance d' the same observations hold for country 2.

The above two statements are equivalent with the operation of replacing the unmeasurable benefit of forming a link with a change in the fixed costs associated with the network, subsequently leading to the empirical prediction. By assuming existence of increasing returns to scale in the transport sector and variable fixed costs in transportation, the benefit of forming a link can be represented by changes in fixed costs stemming from the decision of the firm to trade directly or indirectly. This alternative setting confirms qualitatively the main theoretical exposition where the presence of a transportation sector can be avoided by assuming the existence of benefits and costs associated with links.

A.2.5 The number of transport firms

For completeness, I close the model by characterising the number of transport firms. For country 3, the partial equilibrium price and output can then be utilised to extract the number of firms. The former satisfies the full employment condition and is shown to be:

$$n_3^t = \frac{L^t}{F_3^t}(1-\theta)\frac{d\theta+1}{d\theta+1-\theta}$$

For country 1, expressing output in common units of q_{31} we have:

$$n_1^t = \frac{L^t}{F_1^t}(1-\theta) \times \left[(1-\theta) + K\frac{1}{2}\frac{F_3^t}{F_1^t}\right]^{-1} \tag{A.8}$$

where $K(d,d')$[3] is a function of the distances between trading partners. The term K is increasing in d and decreasing in d'. The number of transport firms as shown below is decreasing in d which is what one should expect since by virtue of the second statement more labour is required to be allocated to accommodate an increase in F_1^t. The change in the number of transport firms is ambiguous wrt to changes in d'. It will be determined by the level of the ratio of fixed costs. If the ratio of fixed costs is substantially large implying the level of fixed costs of the connecting country is small then the number of transport firms is decreasing in d'. If the level of fixed costs of the connecting country is large then the ratio becomes small implying an increase in the number of transport firms. This arises because there is an increase in labour input due to the increase occurring in d' and a decrease in labour input as a result of a reduction of fixed costs of the connecting country. Hence the number of firms will crucially depend on the level of the ratio of fixed costs.

Proof.

$$\frac{\partial n_1^t}{\partial d} = -\frac{L^t}{F_1^t}(1-\theta)\left[(1-\theta)+K\frac{1}{2}\frac{F_3^t}{F_1^t}\right]^{-2}\frac{1}{2}\left(\frac{\partial K}{\partial d}\frac{F_3^t}{F_1^t} + K\frac{\partial \frac{F_3^t}{F_1^t}}{\partial d}\right)$$

---

[3] $K = \frac{\theta(d+d')\left(\frac{1}{\theta}+d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta}+d\right)^{\frac{\theta}{\theta-1}}}, \qquad \frac{\partial K}{\partial d} = \theta\left[\frac{\left(\frac{1}{\theta}+d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta}+d\right)^{\frac{\theta}{\theta-1}}} + \frac{1}{1-\theta}\frac{(d+d')\left(\frac{1}{\theta}+d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta}+d\right)^{\frac{1-2\theta}{1-\theta}}}\right] > 0,$

$\frac{\partial K}{\partial d'} = \frac{\theta\left(\frac{1}{\theta}+d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta}+d\right)^{\frac{\theta}{\theta-1}}}\left[1 - \frac{1}{1-\theta}(d+d')\left(\frac{1}{\theta}+d'\right)^{\frac{1+\theta}{1-\theta}}\right] < 0$

The last term in brackets can be rearranged to write:

$$M = \theta \frac{F_3^t}{F_1^t} \left[\frac{\left(\frac{1}{\theta} + d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta} + d\right)^{\frac{\theta}{\theta-1}}} + \frac{(d+d')\left(\frac{1}{\theta} + d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta} + d\right)^{\frac{1-2\theta}{1-\theta}}} \left(1 + \frac{1}{1-\theta} \times \Lambda\right) \right] > 0$$

where

$$\Lambda = 1 - \frac{(1-\theta)(\frac{1}{\theta} + d) + \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}} \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}} \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}}} > 0$$

since the fraction is clearly less than unity.

$$\frac{\partial n_1^t}{\partial d'} = -\frac{L^t}{F_1^t}(1-\theta) \left[(1-\theta) + K \frac{1}{2} \frac{F_3^t}{F_1^t}\right]^{-2} \frac{1}{2} \left(\frac{\partial K}{\partial d'} \frac{F_3^t}{F_1^t} + K \frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} \right)$$

The last term in brackets can be rewritten as:

$$M' = \frac{\theta \left(\frac{1}{\theta} + d'\right)^{\frac{1}{\theta-1}}}{\left(\frac{1}{\theta} + d\right)^{\frac{\theta}{\theta-1}}} \left[1 - (d+d') \left(\frac{1}{1-\theta} \left(\frac{1}{\theta} + d'\right)^{\frac{1+\theta}{1-\theta}} - \frac{\partial \frac{F_3^t}{F_1^t}}{\partial d'} \right) \right]$$

Expanding the partial derivative of fixed costs wrt d' and grouping terms, the expression in large brackets becomes:

$$\Lambda' = \frac{1}{1-\theta} \left(\frac{1}{\theta} + d'\right)^{\frac{1+\theta}{1-\theta}} \left(1 - \theta \frac{F_3^t}{F_1^t} \left(\frac{1}{\theta} + d'\right)^{-\frac{2+\theta}{1-\theta}} \frac{\left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}}{\frac{1}{\theta} + d + \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}}} \right)$$

where the magnitude of the ratio of fixed costs will determine whether the term in brackets is positive or negative since all other terms are less than unity. The ratio of fixed costs is greater than unity since $d' > d$: $\frac{F_3^t}{F_1^t} = 2 \frac{\left(\frac{1}{\theta}+d\right)}{\frac{1}{\theta}+d+\left(\frac{1}{\theta}+d'\right)^{\frac{\theta}{\theta-1}}\left(\frac{1}{\theta}+d\right)^{\frac{1}{1-\theta}}} \geq 1 \Leftrightarrow$
$\frac{1}{\theta} + d \geq \left(\frac{1}{\theta} + d'\right)^{\frac{\theta}{\theta-1}} \left(\frac{1}{\theta} + d\right)^{\frac{1}{1-\theta}} \Leftrightarrow$
$\left(\frac{1}{\theta} + d\right)^{-\frac{\theta}{1-\theta}} \geq \left(\frac{1}{\theta} + d'\right)^{-\frac{\theta}{1-\theta}}$ which can only hold if $d' \geq d$, which is true.

Therefore if the magnitude is such that $\Lambda' < 0$ then $M' > 0$ and hence $\frac{\partial n_1^t}{\partial d'} < 0$: the number of transport firms are decreasing in d'. If the magnitude of the ratio of fixed costs is such that $\Lambda' > 0$ then $M' < 0$ and the number of transport firms are increasing in d'. $\square$

A.3 Comparison of distance variables

A.3.1 1 digit level

Table A.1: Exports: Impact of direct capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Direct Distance	-0.783***	-1.336***	-0.723***	-1.295***	-1.091***	-1.402***
	(0.203)	(0.177)	(0.178)	(0.157)	(0.204)	(0.184)
Common Language	0.793**	0.534***	1.173***	0.692***	1.185***	1.088***
	(0.316)	(0.197)	(0.220)	(0.170)	(0.301)	(0.247)
Contiguity	0.346	-0.359	0.0861	-0.337	0.188	-0.942
	(0.789)	(0.574)	(0.779)	(0.578)	(0.801)	(0.921)
Exporter's GDP	1.027***		1.082***		1.242***	
	(0.0517)		(0.0405)		(0.0614)	
Importer's GDP	1.067***		1.069***		0.809***	
	(0.0412)		(0.0367)		(0.0736)	
Fixed Effects						
Exporter-Importer	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,595	1,606	1,522	1,522	977	977
R-squared	0.680	0.909	0.787	0.932	0.701	0.915

Pooled OLS estimation for years 2003 − 2007, monetary units are real US Dollars, aggregation level is HS1. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area.

Table A.2: Exports: Impact of indirect capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-1.036***	-1.325***	-0.796***	-1.312***	-1.304***	-1.473***
	(0.269)	(0.235)	(0.231)	(0.201)	(0.227)	(0.161)
Common Language	0.716**	0.556***	1.162***	0.725***	1.187***	1.129***
	(0.321)	(0.213)	(0.229)	(0.188)	(0.308)	(0.258)
Contiguity	0.827	0.641	0.632	0.604	0.732**	-0.362
	(0.684)	(0.395)	(0.670)	(0.415)	(0.358)	(0.402)
Exporter's GDP	1.055***		1.101***		1.249***	
	(0.0517)		(0.0418)		(0.0605)	
Importer's GDP	1.112***		1.106***		0.815***	
	(0.0423)		(0.0370)		(0.0731)	
Fixed Effects						
Exporter-Importer	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,595	1,606	1,522	1,522	977	977
R-squared	0.682	0.903	0.785	0.927	0.704	0.913
P-values Ho: See A	0.34	0.96	0.75	0.93	0.34	0.65

Pooled OLS estimation for years 2003 − 2007, monetary units are real US Dollars, aggregation level is HS1. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *A***: Coefficient of direct distance=Coefficient of indirect distance.

A.3.2 2 digit level

Table A.3: Exports: Impact of direct capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Direct Distance	-0.822***	-1.340***	-0.856***	-1.291***	-0.973***	-1.481***
	(0.136)	(0.134)	(0.114)	(0.125)	(0.166)	(0.147)
Common Language	0.769***	0.853***	0.767***	0.851***	0.869***	1.158***
	(0.162)	(0.137)	(0.126)	(0.120)	(0.173)	(0.151)
Contiguity	0.974**	0.625	0.892**	0.619	0.616	0.133
	(0.442)	(0.535)	(0.356)	(0.464)	(0.397)	(0.378)
Exporter's GDP	0.917***		0.904***		0.736***	
	(0.0321)		(0.0261)		(0.0550)	
Importer's GDP	0.742***		0.741***		0.684***	
	(0.0322)		(0.0257)		(0.0560)	
Fixed Effects						
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72,844	73,139	69,306	69,306	34,514	34,514
R-squared	0.348	0.610	0.424	0.644	0.226	0.492

Pooled OLS estimation for years 2003 – 2007, monetary units are real US Dollars, aggregation level is HS2. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area.

Table A.4: Exports: Impact of indirect capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-0.965***	-1.537***	-0.991***	-1.502***	-1.144***	-1.520***
	(0.177)	(0.167)	(0.148)	(0.154)	(0.192)	(0.146)
Common Language	0.711***	0.819***	0.711***	0.816***	0.850***	1.121***
	(0.166)	(0.146)	(0.132)	(0.128)	(0.173)	(0.158)
Contiguity	1.533***	1.460***	1.491***	1.425***	0.807**	0.158
	(0.416)	(0.510)	(0.339)	(0.440)	(0.327)	(0.281)
Exporter's GDP	0.942***		0.930***		0.743***	
	(0.0329)		(0.0272)		(0.0541)	
Importer's GDP	0.795***		0.796***		0.695***	
	(0.0306)		(0.0249)		(0.0540)	
Fixed Effects						
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72,844	73,139	69,306	69,306	34,514	34,514
R-squared	0.347	0.608	0.422	0.642	0.228	0.491
P-values Ho: See A	0.42	0.24	0.36	0.17	0.37	0.79

Pooled OLS estimation for years 2003 – 2007, monetary units are real US Dollars, aggregation level is HS2. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *A***: Coefficient of direct distance=Coefficient of indirect distance.

A.3.3 6 digit level

Table A.5: Exports: Impact of direct capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Direct Distance	-0.432***	-0.897***	-0.439***	-0.863***	-0.592***	-0.816***
	(0.120)	(0.147)	(0.108)	(0.128)	(0.152)	(0.102)
Common Language	0.276*	0.539***	0.217	0.436***	-0.0620	0.398***
	(0.154)	(0.189)	(0.132)	(0.153)	(0.187)	(0.119)
Contiguity	0.516	0.477	0.580	0.417	-0.0495	0.0205
	(0.514)	(0.612)	(0.408)	(0.490)	(0.317)	(0.197)
Exporter's GDP	0.529***		0.495***		0.393***	
	(0.0329)		(0.0288)		(0.0493)	
Importer's GDP	0.537***		0.545***		0.484***	
	(0.0305)		(0.0265)		(0.0501)	
		Fixed Effects				
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	97,711	97,711	93,277	93,277	46,764	46,764
R-squared	0.168	0.376	0.213	0.399	0.101	0.352

OLS estimation for year 2006, monetary units are real US Dollars, aggregation level is HS6. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area.

Table A.6: Exports: Impact of indirect capital distance

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-0.514***	-0.866***	-0.505***	-0.847***	-0.659***	-0.759***
	(0.132)	(0.186)	(0.120)	(0.168)	(0.150)	(0.106)
Common Language	0.238	0.473**	0.183	0.371**	-0.110	0.391***
	(0.160)	(0.217)	(0.137)	(0.181)	(0.176)	(0.112)
Contiguity	0.741	1.046	0.819*	0.957*	0.200	-0.0450
	(0.542)	(0.637)	(0.447)	(0.530)	(0.322)	(0.279)
Exporter's GDP	0.543***		0.507***		0.402***	
	(0.0310)		(0.0273)		(0.0496)	
Importer's GDP	0.561***		0.567***		0.507***	
	(0.0300)		(0.0261)		(0.0486)	
		Fixed Effects				
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	97,711	97,711	93,277	93,277	46,764	46,764
R-squared	0.168	0.372	0.212	0.394	0.101	0.350
P-values Ho: See A	0.53	0.86	0.58	0.92	0.65	0.59

OLS estimation for year 2006, monetary units are real US Dollars, aggregation level is HS6. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *A***: Coefficient of direct distance=Coefficient of indirect distance.

A.4 Indirect distance with hub interaction term

A.4.1 1 digit level

Table A.7: Exports: Indirect with interaction

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-1.387***	-1.729***	-1.035***	-1.630***	-1.757***	-1.695***
	(0.354)	(0.273)	(0.306)	(0.226)	(0.298)	(0.187)
Indirect*Hub	1.005*	1.217***	0.699	0.962***	1.156**	0.683**
	(0.559)	(0.397)	(0.485)	(0.351)	(0.491)	(0.323)
Common Language	0.714**	0.534**	1.164***	0.708***	1.140***	1.105***
	(0.322)	(0.212)	(0.228)	(0.185)	(0.300)	(0.250)
Contiguity	0.685	0.481	0.537	0.479	0.498	-0.475
	(0.682)	(0.401)	(0.666)	(0.417)	(0.346)	(0.387)
Exporter's GDP	1.057***		1.100***		1.242***	
	(0.0519)		(0.0422)		(0.0610)	
Importer's GDP	1.111***		1.105***		0.803***	
	(0.0421)		(0.0367)		(0.0712)	
Fixed Effects						
Exporter-Importer	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,595	1,606	1,522	1,522	977	977
R-squared	0.685	0.906	0.786	0.929	0.712	0.915
P-values Ho: See B	0	0	0	0	0	0
P-values Ho: See C	0.35	0.01	0.30	0.03	0.21	0.14

Pooled OLS estimation for years 2003 – 2007, monetary units are real US Dollars, aggregation level is HS1. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *B***: Coefficient of indirect distance=Coefficient of interaction=0. **Null Hypothesis *C***: Coefficient of direct capital distance (Table A.1)=Coefficient of indirect capital distance plus coefficient of interaction.

A.4.2 2 digit level

Table A.8: Exports: Indirect distance with interaction

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-1.168***	-1.794***	-1.164***	-1.725***	-1.286***	-1.676***
	(0.217)	(0.181)	(0.180)	(0.169)	(0.239)	(0.158)
Indirect*Hub	0.715*	0.929***	0.607*	0.811***	0.449	0.540***
	(0.383)	(0.275)	(0.323)	(0.260)	(0.342)	(0.185)
Common Language	0.730***	0.804***	0.728***	0.804***	0.854***	1.108***
	(0.165)	(0.142)	(0.131)	(0.126)	(0.172)	(0.154)
Contiguity	1.464***	1.355***	1.431***	1.328***	0.741**	-0.0132
	(0.426)	(0.516)	(0.352)	(0.449)	(0.363)	(0.334)
Exporter's GDP	0.943***		0.931***		0.737***	
	(0.0326)		(0.0268)		(0.0538)	
Importer's GDP	0.799***		0.799***		0.691***	
	(0.0304)		(0.0248)		(0.0523)	
			Fixed Effects			
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72,844	73,139	69,306	69,306	34,514	34,514
R-squared	0.348	0.610	0.423	0.643	0.230	0.493
P-values Ho: See B	0	0	0	0	0	0
P-values Ho: See C	0.22	0.03	0.24	0.06	0.60	0.04

Pooled OLS estimation for years $2003-2007$, monetary units are real US Dollars, aggregation level is HS2. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *B***: Coefficient of indirect distance=Coefficient of interaction=0. **Null Hypothesis *C***: Coefficient of direct capital distance (Table A.3)=Coefficient of indirect capital distance plus coefficient of interaction.

A.4.3 6 digit level

Table A.9: Exports: Indirect distance with interaction

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-0.466***	-0.991***	-0.462***	-0.949***	-0.774***	-0.902***
	(0.170)	(0.197)	(0.153)	(0.181)	(0.156)	(0.120)
Indirect*Hub	-0.204	0.559**	-0.177	0.457**	0.393	0.391***
	(0.260)	(0.263)	(0.237)	(0.228)	(0.242)	(0.115)
Common Language	0.242	0.426**	0.186	0.332*	-0.116	0.360***
	(0.158)	(0.215)	(0.136)	(0.179)	(0.166)	(0.107)
Contiguity	0.741	1.047*	0.820*	0.961*	0.207	-0.302
	(0.549)	(0.617)	(0.451)	(0.514)	(0.338)	(0.332)
Exporter's GDP	0.540***		0.505***		0.392***	
	(0.0306)		(0.0268)		(0.0474)	
Importer's GDP	0.557***		0.565***		0.500***	
	(0.0302)		(0.0261)		(0.0456)	
Fixed Effects						
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	97,711	97,711	93,277	93,277	46,764	46,764
R-squared	0.168	0.372	0.212	0.395	0.102	0.351
P-values Ho: See B	0.02	0	0	0	0	0
P-values Ho: See C	0.22	0.05	0.27	0.06	0.30	0.01

OLS estimation for year 2006, monetary units are real US Dollars, aggregation level is HS6. Standard errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *B***: Coefficient of indirect distance=Coefficient of interaction=0. **Null Hypothesis *C***: Coefficient of direct capital distance (Table A.5)=Coefficient of indirect capital distance plus coefficient of interaction.

A.5 Results for endogenous interaction term

A.5.1 1 digit level

Table A.10: Exports: Indirect distance with interaction

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-1.774***	-1.954***	-1.553***	-1.908***	-1.993***	-1.824***
	(0.253)	(0.149)	(0.219)	(0.108)	(0.205)	(0.0957)
Indirect*Hub	2.113***	1.721***	2.217***	1.487***	1.757***	0.886***
	(0.557)	(0.250)	(0.442)	(0.205)	(0.413)	(0.184)
Common Language	0.712***	0.607***	1.170***	0.791***	1.116***	1.156***
	(0.171)	(0.129)	(0.118)	(0.107)	(0.155)	(0.140)
Contiguity	0.529	0.247	0.329	0.226	0.376	-0.626***
	(0.332)	(0.296)	(0.323)	(0.291)	(0.243)	(0.217)
Exporter's GDP	1.059***		1.099***		1.239***	
	(0.0264)		(0.0217)		(0.0310)	
Importer's GDP	1.109***		1.103***		0.797***	
	(0.0208)		(0.0179)		(0.0352)	
			Fixed Effects			
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,595	1,029	1,522	978	977	511
R-squared	0.681	0.894	0.779	0.927	0.710	0.913
P-values Ho: See B	0	0	0	0	0	0
P-values Ho: See C	0	0	0	0	0	0
Hausman P-value	0.0366	0	0	0	0.8	0

2SLS estimation for years $2003 - 2007$, monetary units are real US Dollars, aggregation level is HS1. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns $(1), (2)$ display outcomes of the non-robust sample. Columns $(3), (4)$ display outcomes of the sample with 2 studentised residuals removed. Columns $(5), (6)$ display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *B***: Coefficient of indirect distance=Coefficient of interaction=0. **Null Hypothesis *C***: Coefficient of direct capital distance (Table A.5)=Coefficient of indirect capital distance plus coefficient of interaction. **Hausman Test Null Hypothesis**: The specified endogenous regressors can actually be treated as exogenous.

A.5.2 2 digit level

Table A.11: Exports: Indirect distance with interaction

Variable	(1) Exports	(2) Exports	(3) Exports	(4) Exports	(5) Exports	(6) Exports
Indirect Distance	-1.417***	-1.966***	-1.405***	-1.875***	-1.342***	-1.729***
	(0.0390)	(0.0331)	(0.0335)	(0.0297)	(0.0419)	(0.0410)
Indirect*Hub	1.591***	1.450***	1.457***	1.282***	0.625***	0.677***
	(0.101)	(0.0613)	(0.0871)	(0.0544)	(0.0946)	(0.0685)
Common Language	0.754***	0.899***	0.750***	0.899***	0.855***	1.225***
	(0.0267)	(0.0331)	(0.0232)	(0.0300)	(0.0347)	(0.0484)
Contiguity	1.378***	0.774***	1.347***	0.863***	0.715***	-0.130
	(0.0651)	(0.0725)	(0.0570)	(0.0643)	(0.0837)	(0.102)
Exporter's GDP	0.944***		0.932***		0.735***	
	(0.00561)		(0.00498)		(0.0107)	
Importer's GDP	0.803***		0.803***		0.689***	
	(0.00520)		(0.00454)		(0.0109)	
Fixed Effects						
Exporter-Importer-Sector	No	Yes	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72,844	56,338	69,306	53,702	34,514	23,026
R-squared	0.346	0.623	0.421	0.649	0.229	0.494
P-values Ho: See B	0	0	0	0	0	0
P-values Ho: See C	0	0	0	0	0	0
Hausman P-value	0	0	0	0	0.0146	0

2SLS estimation for years 2003 − 2007, monetary units are real US Dollars, aggregation level is HS2. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported. Columns (1), (2) display outcomes of the non-robust sample. Columns (3), (4) display outcomes of the sample with 2 studentised residuals removed. Columns (5), (6) display outcomes of the sample with 2 studentised residuals removed and exclude the US and the EU 15 area. **Null Hypothesis *B***: Coefficient of indirect distance=Coefficient of interaction=0. **Null Hypothesis *C***: Coefficient of direct capital distance (Table A.5)=Coefficient of indirect capital distance plus coefficient of interaction. **Hausman Test Null Hypothesis**: The specified endogenous regressors can actually be treated as exogenous.

A.6 Additional data details

Table A.12: Trade partnerships with finite port distance

Exporter	Importer	Exporter	Importer	Exporter	Importer	Exporter	Importer	Exporter	Importer	Exporter	Importer
ARE	AUS	CAN	MYS	ECU	USA	ISL	ARG	MYS	USA	THA	USA
ARE	EU15	CAN	NZL	EGY	AUS	ISL	AUS	NGA	AUS	TUN	AUS
ARE	IND	CAN	PAK	EGY	USA	ISL	BRA	NZL	ARG	TUN	USA
ARE	NZL	CAN	PER	EU15	ARE	ISL	COL	NZL	AUS	TUR	ARG
ARE	USA	CAN	RUS	EU15	ARG	ISL	ECU	NZL	BRA	TUR	AUS
ARG	AUS	CAN	SAU	EU15	AUS	ISL	NZL	NZL	COL	TUR	BRA
ARG	COL	CAN	TUN	EU15	BGD	ISL	PER	NZL	ECU	TUR	COL
ARG	ECU	CAN	TWN	EU15	BRA	ISL	URY	NZL	PER	TUR	ECU
ARG	EU15	CAN	URY	EU15	CHN	ISL	USA	NZL	URY	TUR	NZL
ARG	MEX	CAN	VEN	EU15	COL	ISR	ARG	NZL	USA	TUR	PER
ARG	NZL	CAN	ZAF	EU15	ECU	ISR	AUS	PER	AUS	TUR	URY
ARG	PER	CHE	ARG	EU15	EGY	ISR	BRA	PER	NZL	TUR	USA
ARG	USA	CHE	AUS	EU15	IDN	ISR	COL	PER	USA	TWN	AUS
AUS	ARG	CHE	BRA	EU15	IND	ISR	ECU	PHL	AUS	UKR	AUS
AUS	BGD	CHE	COL	EU15	JOR	ISR	NZL	PHL	EU15	UKR	USA
AUS	BRA	CHE	ECU	EU15	JPN	ISR	PER	PHL	USA	URY	AUS
AUS	CHN	CHE	NZL	EU15	KOR	ISR	URY	POL	ARG	URY	NZL
AUS	COL	CHE	PER	EU15	LBY	ISR	USA	POL	AUS	URY	USA
AUS	ECU	CHE	URY	EU15	MAR	JPN	ARG	POL	BRA	USA	ARG
AUS	EGY	CHE	USA	EU15	MYS	JPN	AUS	POL	COL	USA	AUS
AUS	IDN	CHL	AUS	EU15	NZL	JPN	BRA	POL	ECU	USA	BRA
AUS	JPN	CHL	BRA	EU15	PER	JPN	COL	POL	NZL	USA	CHN
AUS	KOR	CHL	COL	EU15	PHL	JPN	ECU	POL	PER	USA	COL
AUS	LKA	CHL	ECU	EU15	SAU	JPN	EU15	POL	URY	USA	ECU
AUS	NZL	CHL	NZL	EU15	SDN	JPN	NZL	POL	USA	USA	EGY
AUS	PAK	CHL	URY	EU15	SGP	JPN	PER	RUS	AUS	USA	EU15
AUS	PER	CHL	USA	EU15	THA	JPN	URY	RUS	USA	USA	IDN
AUS	SAU	CHN	ARG	EU15	TUN	JPN	USA	SAU	AUS	USA	IND
AUS	TWN	CHN	AUS	EU15	URY	KAZ	AUS	SAU	EU15	USA	JPN
AUS	URY	CHN	BRA	EU15	USA	KOR	ARG	SAU	USA	USA	KOR
AUS	USA	CHN	COL	EU15	VNM	KOR	AUS	SGP	AUS	USA	LKA
AUS	ZAF	CHN	ECU	EU15	YEM	KOR	BRA	SGP	EU15	USA	MAR
BGD	AUS	CHN	EU15	GHA	AUS	KOR	COL	SGP	NZL	USA	MYS
BGD	USA	CHN	IND	HUN	ARG	KOR	ECU	SGP	USA	USA	NZL
BGR	USA	CHN	NZL	HUN	AUS	KOR	NZL	SVK	ARG	USA	PAK
BHR	AUS	CHN	PER	HUN	BRA	KOR	PER	SVK	AUS	USA	PER
BOL	AUS	CHN	URY	HUN	COL	KOR	URY	SVK	BRA	USA	PHL
BOL	NZL	CHN	USA	HUN	ECU	KOR	USA	SVK	COL	USA	RUS
BOL	USA	COL	AUS	HUN	NZL	KWT	AUS	SVK	ECU	USA	SAU
BRA	EU15	COL	NZL	HUN	PER	LBN	AUS	SVK	NZL	USA	SGP
CAN	ARG	COL	USA	HUN	URY	LKA	AUS	SVK	PER	USA	THA
CAN	AUS	CRI	AUS	HUN	USA	LKA	USA	SVK	URY	USA	TUN
CAN	BRA	CRI	COL	IDN	AUS	LTU	AUS	SVK	USA	USA	URY
CAN	CHN	CRI	ECU	IDN	EU15	MAR	AUS	SVN	ARG	USA	VEN
CAN	COL	CZE	ARG	IDN	USA	MAR	USA	SVN	AUS	USA	VNM
CAN	DZA	CZE	AUS	IND	AUS	MEX	ARG	SVN	BRA	USA	YEM
CAN	ECU	CZE	BRA	IND	BRA	MEX	AUS	SVN	COL	USA	ZAF
CAN	EGY	CZE	COL	IND	CHN	MEX	BRA	SVN	ECU	VEN	AUS
CAN	EU15	CZE	ECU	IND	COL	MEX	COL	SVN	NZL	VEN	USA
CAN	IDN	CZE	NZL	IND	ECU	MEX	ECU	SVN	PER	VNM	AUS
CAN	IRN	CZE	PER	IND	EU15	MEX	NZL	SVN	URY	VNM	EU15
CAN	JOR	CZE	URY	IND	NZL	MEX	PER	SVN	USA	VNM	USA
CAN	JPN	CZE	USA	IND	PER	MEX	URY	THA	ARG	YEM	USA
CAN	KOR	DOM	USA	IND	SAU	MYS	AUS	THA	AUS	ZAF	ARG
CAN	LKA	DZA	USA	IND	URY	MYS	BRA	THA	BRA	ZAF	AUS
CAN	MAR	ECU	AUS	IND	USA	MYS	EU15	THA	EU15	ZAF	NZL
CAN	MEX	ECU	NZL	IRN	AUS	MYS	NZL	THA	NZL	ZAF	USA

Table A.13: Commodities traded

Agriculture		Crude oils		Raw Materials		Manufactures	
Commodity	Transport Mode	Commodity	Transport Mode	Commodity	Transport Mode	Commodity	Transport Mode
01: Live animals	Containers	27: Mineral fuels, oils, distillation products, etc	Dirty bulk	25: Salt, sulphur, earth, stone, plaster, lime and cement	Dirty bulk	15: Animal,vegetable fats and oils, cleavage products, et	Dirty bulk
02: Meat and edible meat offal	Containers	27: Mineral fuels, oils, distillation products, etc	Tankers	26: Ores, slag and ash	Dirty bulk	15: Animal,vegetable fats and oils, cleavage products, et	Containers
03: Fish, crustaceans, molluscs, aquatic invertebrates ne	Containers			72: Iron and steel	Dirty bulk	28: Inorganic chemicals, precious metal compound, isotope	Dirty bulk
04: Dairy products, eggs, honey, edible animal product ne	Containers					29: Organic chemicals	Dirty bulk
05: Products of animal origin, nes	Containers					30: Pharmaceutical products	Containers
06: Live trees, plants, bulbs, roots, cut flowers etc	Containers					31: Fertilizers	Dirty bulk
07: Edible vegetables and certain roots and tubers	Containers					32: Tanning, dyeing extracts, tannins, derivs,pigments et	Containers
08: Edible fruit, nuts, peel of citrus fruit, melons	Containers					33: Essential oils, perfumes, cosmetics, toiletries	Containers
09: Coffee, tea, mate and spices	Containers					34: Soaps, lubricants, waxes, candles, modelling pastes	Containers
10: Cereals	Clean bulk					35: Albuminoids, modified starches, glues, enzymes	Containers
11: Milling products, malt, starches, inulin, wheat glute	Containers					36: Explosives, pyrotechnics, matches, pyrophorics, etc	Containers
12: Oil seed, oleagic fruits, grain, seed, fruit, etc, ne	Clean bulk					37: Photographic or cinematographic goods	Containers
12: Oil seed, oleagic fruits, grain, seed, fruit, etc, ne	Containers					38: Miscellaneous chemical products	Containers
13: Lac, gums, resins, vegetable saps and extracts nes	Containers					39: Plastics and articles thereof	Containers
14: Vegetable plaiting materials, vegetable products nes	Containers					40: Rubber and articles thereof	Containers
15: Animal,vegetable fats and oils, cleavage products, et	Tankers					41: Raw hides and skins (other than furskins) and leather	Containers
15: Animal,vegetable fats and oils, cleavage products, et	Containers					42: Articles of leather, animal gut, harness, travel good	Containers
16: Meat, fish and seafood food preparations nes	Containers					43: Furskins and artificial fur, manufactures thereof	Containers
17: Sugars and sugar confectionery	Containers					44: Wood and articles of wood, wood charcoal	Containers
18: Cocoa and cocoa preparations	Containers					45: Cork and articles of cork	Containers
19: Cereal, flour, starch, milk preparations and products	Containers					46: Manufactures of plaiting material, basketwork, etc.	Containers
20: Vegetable, fruit, nut, etc food preparations	Containers					47: Pulp of wood, fibrous cellulosic material, waste etc	Containers
21: Miscellaneous edible preparations	Containers					48: Paper & paperboard, articles of pulp, paper and board	Containers
22: Beverages, spirits and vinegar	Containers					49: Printed books, newspapers, pictures etc	Containers
23: Residues, wastes of food industry, animal fodder	Containers					50: Silk	Containers
24: Tobacco and manufactured tobacco substitutes	Containers					51: Wool, animal hair, horsehair yarn and fabric thereof	Containers
						52: Cotton	Containers
						53: Vegetable textile fibres nes, paper yarn, woven fabri	Containers
						54: manmade filaments	Containers
						55: manmade staple fibres	Containers
						56: Wadding, felt, nonwovens, yarns, twine, cordage, etc	Containers
						57: Carpets and other textile floor coverings	Containers
						58: Special woven or tufted fabric, lace, tapestry etc	Containers
						59: Impregnated, coated or laminated textile fabric	Containers
						60: Knitted or crocheted fabric	Containers
						61: Articles of apparel, accessories, knit or crochet	Containers
						62: Articles of apparel, accessories, not knit or crochet	Containers
						63: Other made textile articles, sets, worn clothing etc	Containers
						64: Footwear, gaiters and the like, parts thereof	Containers
						65: Headgear and parts thereof	Containers
						66: Umbrellas, walking-sticks, seat-sticks, whips, etc	Containers
						67: Bird skin, feathers, artificial flowers, human hair	Containers
						68: Stone, plaster, cement, asbestos, mica, etc articles	Containers
						69: Ceramic products	Containers
						70: Glass and glassware	Containers
						71: Pearls, precious stones, metals, coins, etc	Containers
						73: Articles of iron or steel	Containers
						74: Copper and articles thereof	Containers
						75: Nickel and articles thereof	Containers
						76: Aluminium and articles thereof	Containers
						78: Lead and articles thereof	Containers
						79: Zinc and articles thereof	Containers
						80: Tin and articles thereof	Containers
						81: Other base metals, cermets, articles thereof	Containers
						82: Tools, implements, cutlery, etc of base metal	Containers
						83: Miscellaneous articles of base metal	Containers
						84: Nuclear reactors, boilers, machinery, etc	Containers
						85: Electrical, electronic equipment	Containers
						86: Railway, tramway locomotives, rolling stock, equipmen	Containers
						87: Vehicles other than railway, tramway	Containers
						88: Aircraft, spacecraft, and parts thereof	Containers
						89: Ships, boats and other floating structures	Containers
						90: Optical, photo, technical, medical, etc apparatus	Containers
						91: Clocks and watches and parts thereof	Containers
						92: Musical instruments, parts and accessories	Containers
						93: Arms and ammunition, parts and accessories thereof	Containers
						94: Furniture, lighting, signs, prefabricated buildings	Containers
						95: Toys, games, sports requisites	Containers
						96: Miscellaneous manufactured articles	Containers
						97: Works of art, collectors pieces and antiques	Containers

Appendix B

B.1 Derivation of the intensive and extensive margin elasticities

By applying the Leibniz rule to relationship (3.8) for a particular sector h, the elasticity of aggregate exports with respect to variable trade costs b_{ij} and fixed costs F_{ij}^M respectively, is decomposed into the intensive and extensive margin elasticities:

$$-\frac{\partial X_{ij}}{\partial b_{ij}}\frac{b_{ij}}{X_{ij}} = \underbrace{-\frac{\mathrm{b_{ij}}}{\mathrm{X_{ij}}}\left[\mathrm{L_i}\int_{\phi^*_{\mathrm{ij}}}^{\infty}\frac{\partial \mathrm{x_{ij}}(\phi)}{\partial \mathrm{b_{ij}}}\mathrm{g}(\phi)\mathrm{d}\phi\right]}_{\text{Intensive Margin Elasticity}} + \underbrace{\frac{\mathrm{b_{ij}}}{\mathrm{X_{ij}}}\left[\mathrm{L_i x}(\phi^*_{\mathrm{ij}})\mathrm{g}(\phi^*_{\mathrm{ij}})\frac{\partial \phi^*_{\mathrm{ij}}}{\partial \mathrm{b_{ij}}}\right]}_{\text{Extensive Margin Elasticity}}$$

$$-\frac{\partial X_{ij}}{\partial F^M_{ij}}\frac{F^M_{ij}}{X_{ij}} = \underbrace{-\frac{\mathrm{F^M_{ij}}}{\mathrm{X_{ij}}}\left[\mathrm{L_i}\int_{\phi^*_{\mathrm{ij}}}^{\infty}\frac{\partial \mathrm{x_{ij}}(\phi)}{\partial \mathrm{F^M_{ij}}}\mathrm{g}(\phi)\mathrm{d}\phi\right]}_{\text{Intensive Margin Elasticity}} + \underbrace{\frac{\mathrm{F^M_{ij}}}{\mathrm{X_{ij}}}\left[\mathrm{L_i x}(\phi^*_{\mathrm{ij}})\mathrm{g}(\phi^*_{\mathrm{ij}})\frac{\partial \phi^*_{\mathrm{ij}}}{\partial \mathrm{F^M_{ij}}}\right]}_{\text{Extensive Margin Elasticity}}$$

For first of two equations given that $\frac{\partial x_{ij}(\phi)}{\partial b_{ij}} = -\frac{\sigma-1}{1+(\gamma+1)(\beta-1)}\frac{x_{ij}(\phi)}{b_{ij}}$, the intensive margin elasticity with respect to b_{ij} is:

$$\begin{aligned}
\widehat{IME_{b_{ij}}} &\equiv \frac{\sigma-1}{1+(\gamma+1)(\beta-1)}\frac{1}{X_{ij}}\left[L_i\int_{\phi^*_{ij}}^{\infty} x_{ij}(\phi)g(\phi)d\phi\right] \\
&= \frac{\sigma-1}{1+(\gamma+1)(\beta-1)}\frac{X_{ij}}{X_{ij}} \\
&= IME_{b_{ij}} \times \text{Shipping Price Effects} \\
&= (\sigma-1)\frac{1}{1+(\gamma+1)(\beta-1)}
\end{aligned}$$

Where $IME_{b_{ij}} = \sigma - 1$ denotes the impact of the specific trade cost which is identical to the Chaney (2008) model of trade as opposed to the constant across trade costs augmented shipping price effects $\frac{1}{1+(\gamma+1)(\beta-1)}$.

Concerning the extensive margin elasticity, since $\frac{\partial \phi^*_{ij}}{\partial b_{ij}} = \frac{1}{1+(\gamma+1)(\beta-1)} \frac{\phi^*_{ij}}{b_{ij}}$ obtain:

$$\begin{aligned}
\widehat{EME_{b_{ij}}} &\equiv \frac{\gamma-(\sigma-1)}{1+(\gamma+1)(\beta-1)} \frac{b_{ij}}{L_i x(\phi^*_{ij}) g(\phi^*_{ij}) \phi^*_{ij}} \frac{L_i x(\phi^*_{ij}) g(\phi^*_{ij}) \phi^*_{ij}}{b_{ij}} \\
&= \frac{\gamma-(\sigma-1)}{1+(\gamma+1)(\beta-1)} \frac{b_{ij}}{X_{ij}} \frac{X_{ij}}{b_{ij}} \\
&= EME_{b_{ij}} \times \text{Shipping Price Effects} \\
&= (\gamma-(\sigma-1)) \frac{1}{1+(\gamma+1)(\beta-1)}
\end{aligned}$$

Following the same procedure for the second of two equations and using the fact that $\frac{\partial x_{ij}(\phi)}{\partial F^M_{ij}} = \frac{(\gamma+1)(\beta-1)}{1+(\gamma+1)(\beta-1)} \frac{x_{ij}(\phi)}{F^M_{ij}}$, the intensive margin elasticity with respect to fixed costs is:

$$\begin{aligned}
\widehat{IME_{F^M_{ij}}} &\equiv -\frac{(\gamma+1)(\beta-1)}{1+(\gamma+1)(\beta-1)} \frac{1}{X_{ij}} \left[L_i \int_{\phi^*_{ij}}^{\infty} x_{ij}(\phi) g(\phi) d\phi \right] \\
&= -\frac{(\gamma+1)(\beta-1)}{1+(\gamma+1)(\beta-1)} \frac{X_{ij}}{X_{ij}} \\
&= IME_{F^M_{ij}} \times \text{Shipping Price Effects} \\
&= -(\gamma+1)(\beta-1) \frac{1}{1+(\gamma+1)(\beta-1)}
\end{aligned}$$

Similarly, given that $\frac{\partial \phi^*_{ij}}{\partial F^M_{ij}} = \frac{1}{\sigma-1} \frac{1}{1+(\gamma+1)(\beta-1)} \frac{\phi^*_{ij}}{F^M_{ij}}$ the extensive margin elasticity becomes:

$$\begin{aligned}
\widehat{EME_{F^M_{ij}}} &\equiv [\gamma-(\sigma-1)] \frac{1}{\sigma-1} \frac{1}{1+(\gamma+1)(\beta-1)} \frac{F^M_{ij}}{L_i x(\phi^*_{ij}) g(\phi^*_{ij}) \phi^*_{ij}} \frac{L_i x(\phi^*_{ij}) g(\phi^*_{ij}) \phi^*_{ij}}{F^M_{ij}} \\
&= [\gamma-(\sigma-1)] \frac{1}{\sigma-1} \frac{1}{1+(\gamma+1)(\beta-1)} \frac{F^M_{ij}}{X_{ij}} \frac{X_{ij}}{F^M_{ij}} \\
&= EME_{F^M_{ij}} \times \text{Shipping Price Effects} \\
&= \left[\frac{\gamma}{\sigma-1} - 1 \right] \frac{1}{1+(\gamma+1)(\beta-1)}
\end{aligned}$$

B.2 Trading countries considered in the empirical estimation

Table B.1: Sample of the trading countries

Exporter	Importer
ARG	ARG
AUS	AUS
BRA	BGD
CAN	BRA
CHL	CHL
JPN	CHN
KOR	COL
NZL	DZA
USA	ECU
	EGY
	HKG
	IDN
	IND
	IRN
	JOR
	JPN
	KOR
	LKA
	MAR
	MEX
	MYS
	NZL
	PAK
	PER
	PHL
	RUS
	SAU
	SGP
	THA
	TUN
	URY
	USA
	VEN
	VNM
	YEM
	ZAF

B.3 Alternative Specification

This section provides preliminary evidence of complementarities between tariff changes and shipping prices across two periods. The first step uses a specification similar to Hummels, Lugovskyy & Skiba (2009) to assess during year 2005, the impact of volume shipped, the factory price of the good and the degree of market power on the additive freight rate. Market power is measured using the elasticity of substitution σ as a proxy, derived using a specification adopted from Hummels, Lugovskyy & Skiba (2009) which is presented in the appendix that follows.

The second step estimates how per unit shipping prices affect the quantity transported in the following year in the presence of tariffs. In this simple exposition we can track the perennial impact of scale effects on transportation which can be induced by trade liberalisation, transportation itself or other exogenous factors.

For the first step the estimating equation is:

$$\ln f_{ijkm} = \eta_0 + \eta_1 \ln(p_{iih}) + \eta_2 \ln(d_{ij}) + \eta_3 \ln \hat{\sigma}_h + \eta_4 \ln q_{ijhm} + \sum_i \alpha_i + \sum_i \alpha_j + \sum_m \alpha_m + e_{ijhm} \text{ for year 2005.}$$

Where $\hat{\sigma}$ is a sector specific estimate of the elasticity of import demand that is used as a proxy for the identifying the presence of market power in transportation. The exporter fixed effect, as in Hummels, Lugovskyy & Skiba (2009), captures the origin specific number of transport firms and controls for country size and infrastructure as does the importer fixed effect. Errors are allowed to be correlated within country pair clusters. Using the same dataset described in section 3.5 the results are presented in table B.2.

Table B.2: Impacts on per unit shipping prices

Variable	(OLS) Per unit shipping prices
F.O.B. price	0.14***
	(0.014)
Distance	0.27***
	(0.045)
Quantity transported	-0.15***
	(0.008)
$\hat{\sigma}$	-0.06**
	(0.015)
Fixed Effects	
Importer	Y
Exporter	Y
Sector	N
Mode	Y
Observations	2,338
R-squared	0.637

Cross sectional OLS estimates for year 2005, monetary units are constant U.S. Dollars. Errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported.

All coefficients are significant at the 1 and 5% levels and have the same signs as Hummels, Lugovskyy & Skiba (2009). A 1% exogenous increase in the quantity transported reduces per unit shipping prices by 0.15% reflecting the presence of scale economies in maritime transportation. Should manufacturing firms become more competitive the markup of transport firms is reduced. Increases in the factory prices of goods raise per unit prices as the marginal cost of shipping increases.

In the subsequent step we can thus assess the impact of the predicted per unit shipping price on next year's quantity transported in the presence of same year tariffs. The estimable equation is:

$$\ln q_{ijkmt} = \iota_0 + \iota_1 \widehat{\ln f}_{ijhm(t-1)} + \iota_2 \ln d_{ij} + \iota_3 \ln b_{ijht} + \sum_i \alpha_i + \sum_j \alpha_j + \sum_m \alpha_m + \tilde{e}_{ijhmt}$$

Where $t = 2006$ and the same error structure is assumed as in the previous step. The results are shown in table B.3.

We cannot draw safe conclusions regarding the generalisation of results due to the substantial loss of information during the two step process. We can preliminary state that increases in the quantity transported in year 2005, possibly accrued through a tariff

Table B.3: Impacts on quantity transported

Variable	(OLS) Quantity transported
Shipping price (predicted)	-3.84***
	(0.19)
Tariff	0.073
	(0.15)
Fixed Effects	
Importer	Y
Exporter	Y
Sector	N
Mode	Y
Observations	499
R-squared	0.754

Cross sectional OLS estimates for year 2005, monetary units are constant U.S. Dollars. Errors are allowed to be correlated within country pair clusters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constants included but not reported.

reduction or a trade cost reduction in that year (yet the tariff variable is insignificant in year 2006) lowered the per unit shipping price. This decrease raises the quantity transported in the following period further and thus there is a perennial feedback across time.

B.4 An estimate of the elasticity of import demand

Using specification (23) of Hummels, Lugovskyy & Skiba (2009) and a methodology described in Hummels (2001), we estimate the slope of the import demand curve using variation in trade costs for each sector h, resulting in a distribution of elasticities $\hat{\sigma}_h$. The estimating relationship is:

$$\ln q_{ijh} = \psi_0 + \sigma_h \ln d_{ij} + \sum_i \alpha_i + \sum_j \alpha_j + \bar{e}_{ijh} \text{ for each } h \in H \tag{B.1}$$

Where σ is identified only from the ij-specific variation of trade cost d_{ij}. The exporter fixed effects control for infrastructure, country size, the number of varieties and unobserved variation in product quality, whilst importer fixed effects control for size and the price index.

There are 3,226 observed sectors at the six digit level, out of which 2,569 regressions yielded a finite estimate of σ. 765 outcomes survive since the p-value of the F-statistic is greater than 5% in the complement cases. The number of observations in the 765 estimations averages 23.55 (standard deviation 8.59) within each sector h.

The 765 observations of $\hat{\sigma}$ have average coefficient size -0.96 (standard deviation 4.15). Dropping all coefficients which have a p-value of the t-statistic greater than 5%, results in only 134 observations of $\hat{\sigma}$, with mean -3.87 (standard deviation 3.70), all of which are strictly negative. The same procedure is applied for year 2006 where the mean value of σ is documented at -3.55 (standard deviation 4.74).

Appendix C

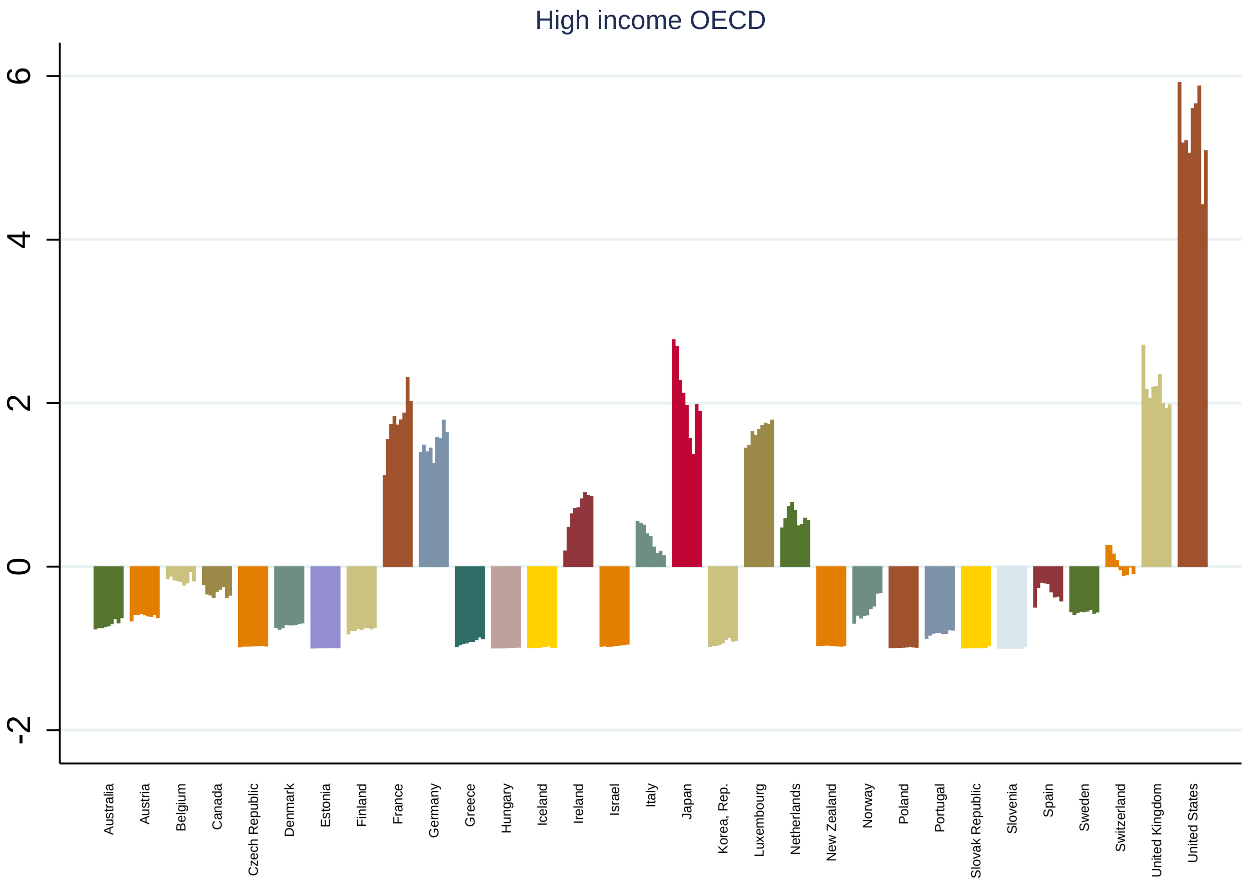
C.1 Countries represented in the network

Table C.1: Countries in the network in 2006

Country	Exposure	Country	Exposure	Country	Exposure
High income OECD	860,880	High income nonOECD	114,672	Upper middle income	15,775
Australia	-70%	Aruba	-100%	Argentina	21%
Austria	-61%	Bahamas, The	-82%	Brazil	-31%
Belgium	-23%	Bahrain	-71%	Bulgaria	-93%
Canada	-28%	Barbados	-82%	Chile	255%
Czech Republic	-97%	Bermuda	283%	Colombia	-47%
Denmark	-72%	Cayman Islands	-26%	Costa Rica	-92%
Estonia	-99%	Channel Islands	80%	Kazakhstan	22%
Finland	-75%	Cyprus	-79%	Latvia	-99%
France	180%	Hong Kong SAR, China	303%	Lebanon	-86%
Germany	159%	Isle of Man	-61%	Malaysia	-56%
Greece	-92%	Kuwait	-86%	Mauritius	366%
Hungary	-99%	Macao SAR, China	-92%	Mexico	-23%
Iceland	-98%	Malta	-89%	Panama	-66%
Ireland	83%	Singapore	101%	Romania	-91%
Israel	-97%			Russian Federation	-26%
Italy	24%	Lower middle income	1,802	South Africa	333%
Japan	157%	Egypt, Arab Rep.	-8%	Thailand	-71%
Luxembourg	173%	India	-82%	Turkey	-80%
Netherlands	50%	Indonesia	-7%	Uruguay	-85%
New Zealand	-97%	Pakistan	-99%	Venezuela, RB	-50%
Norway	-52%	Philippines	293%		
Poland	-99%	Ukraine	-97%	Unclassified	
Portugal	-82%			Gibraltar	
Slovak Republic	-100%			Netherlands Antilles (pre 2009)	
Slovenia	-100%				
Korea, Rep.	-89%				
Spain	-31%				
Sweden	-55%				
Switzerland	-11%				
United Kingdom	235%				
United States	566%				

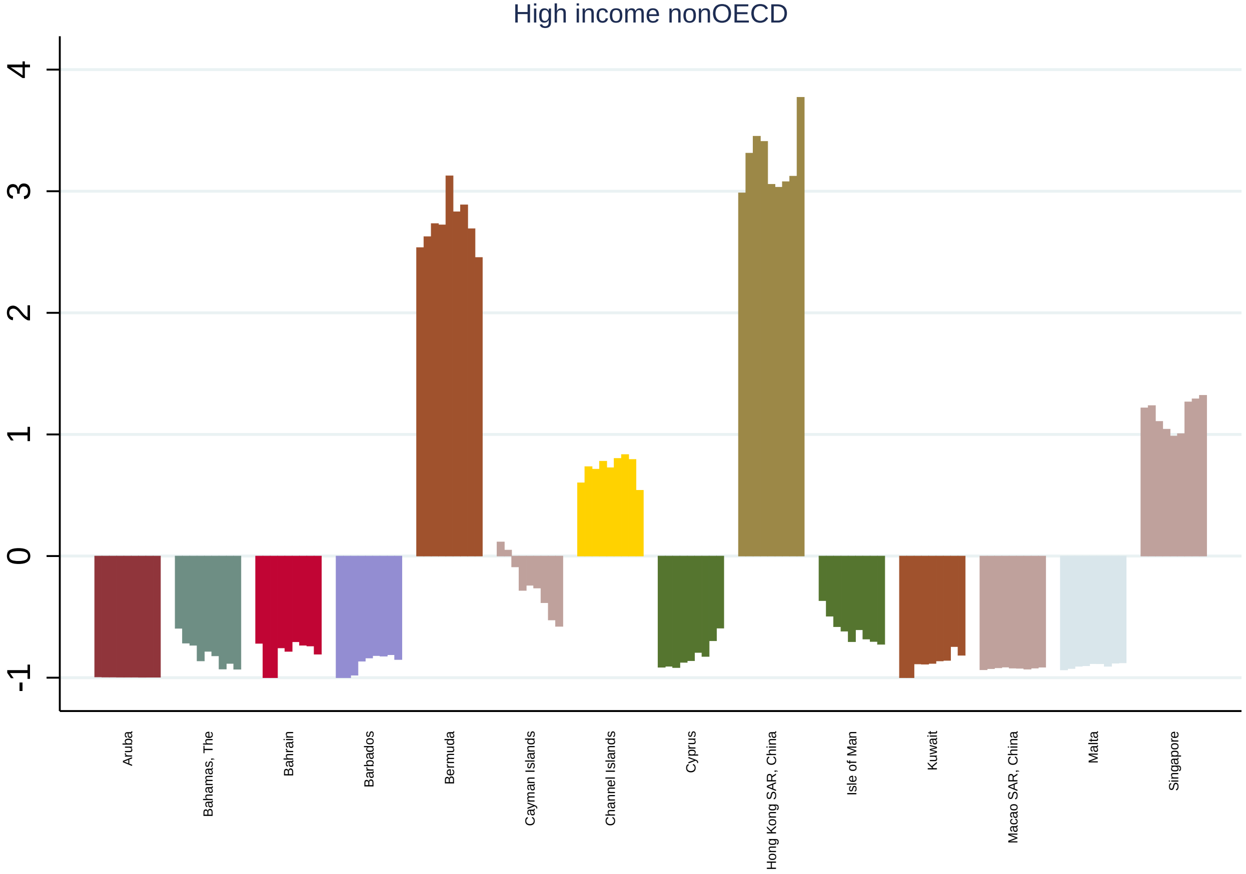
The table presents a cross-section of financial exposures for countries in the network at the end of 2006. Countries are categorised by income group using the World Bank Country classification table (2013). Financial exposures are denoted as the percentage difference from their income group arithmetic mean.

Figure C.1: Exposures by country as percentage differences from their income group arithmetic mean, 2001-2009



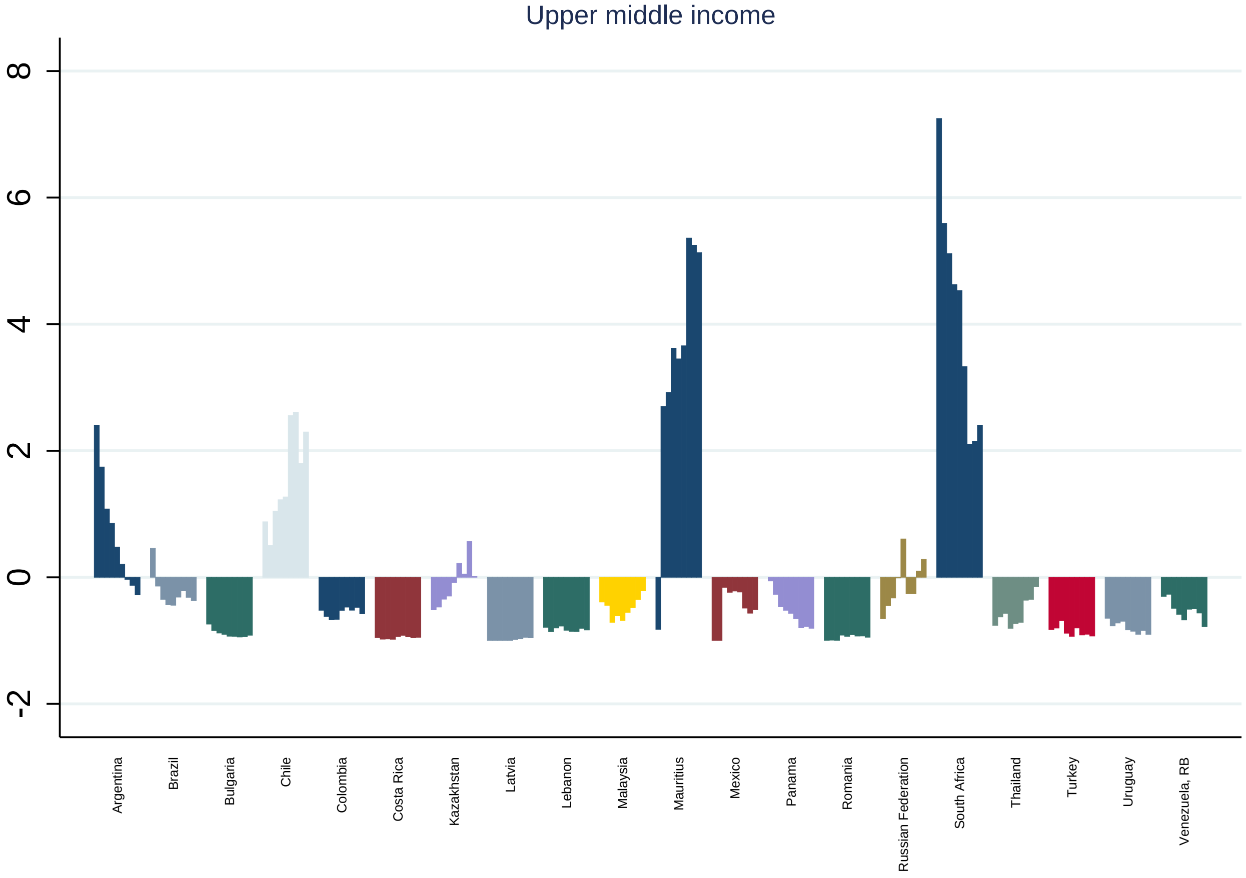
Each bar corresponds to a year. Countries are categorised by income group using the World Bank Country classification table (2013).

Figure C.2: Exposures by country as percentage differences from their income group arithmetic mean, 2001-2009



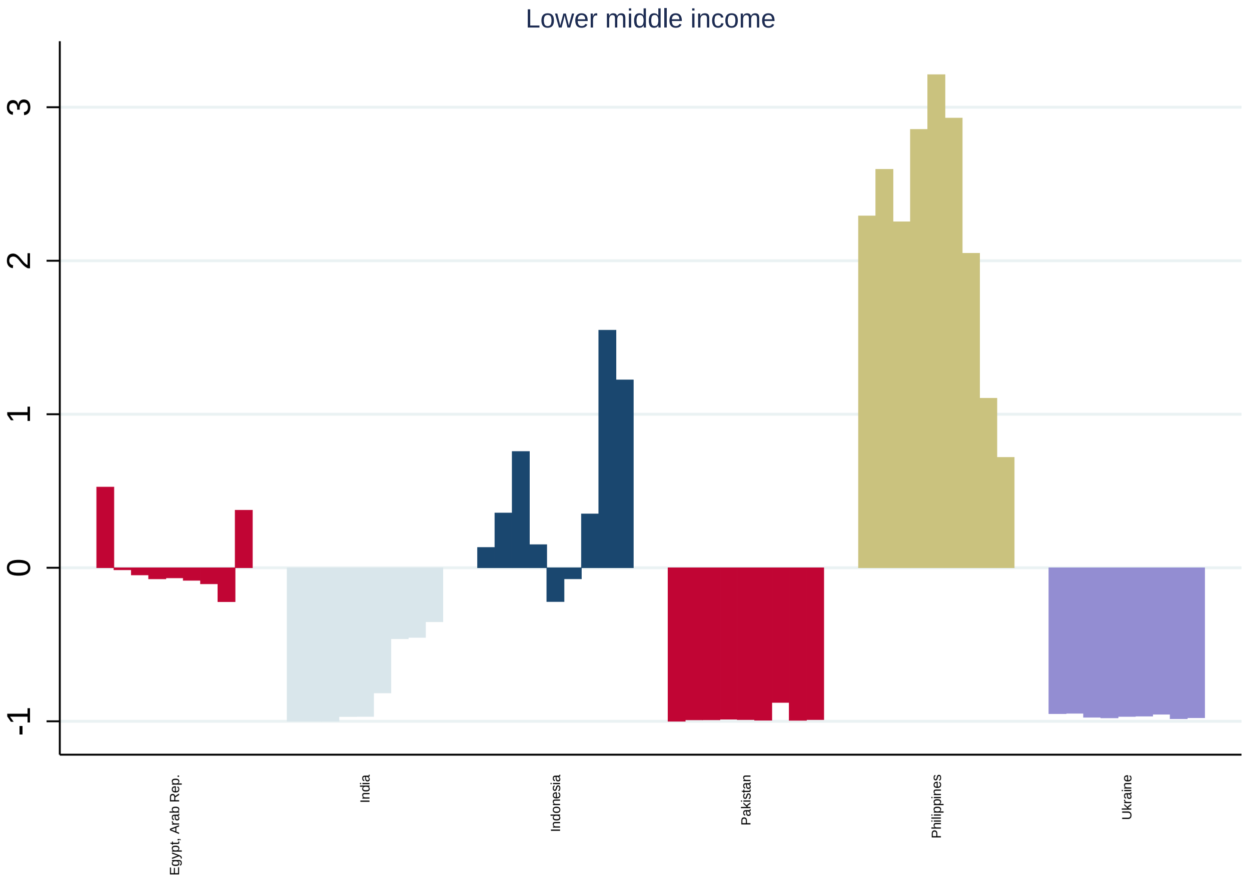
Each bar corresponds to a year. Countries are categorised by income group using the World Bank Country classification table (2013).

Figure C.3: Exposures by country as percentage differences from their income group arithmetic mean, 2001-2009



Each bar corresponds to a year. Countries are categorised by income group using the World Bank Country classification table (2013).

Figure C.4: Exposures by country as percentage differences from their income group arithmetic mean, 2001-2009

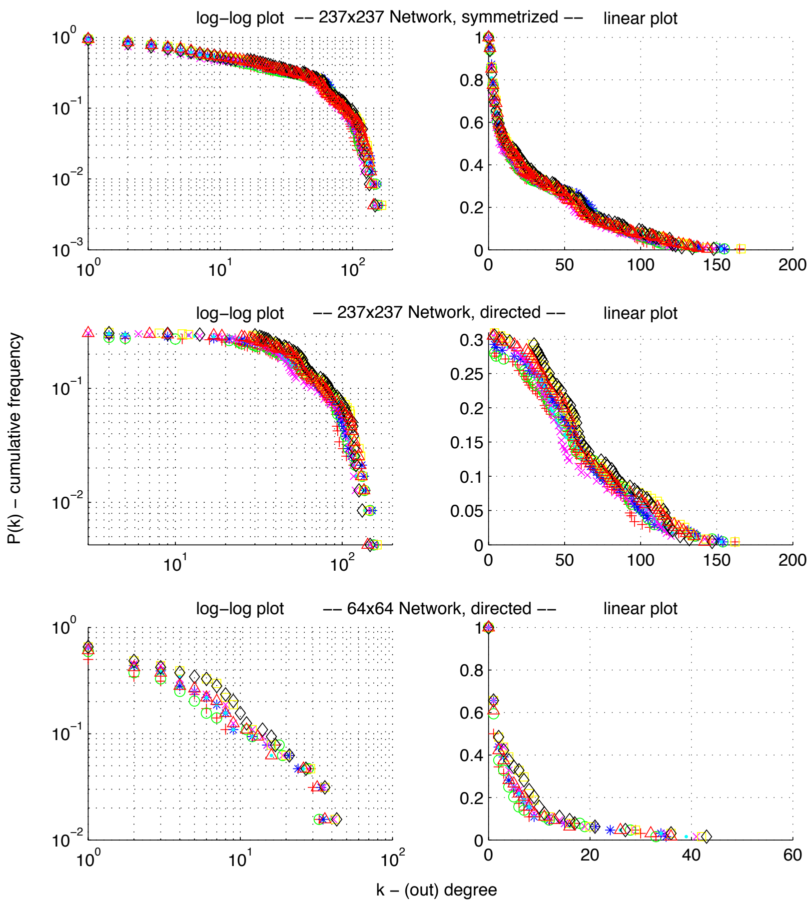


Each bar corresponds to a year. Countries are categorised by income group using the World Bank Country classification table (2013).

C.2 Degree Distributions

In Figure C.5 we show three different cumulative degree distributions for cross border holdings at both linear and logarithmic scaling. The various icons represent the years 2001–2008 (see caption for the key). The first two plots are derived from the full 237×237 CPIS matrix of exposures. The first row comes from symmetrising the network, connecting two countries by an undirected edge if the investment of either country in the other exceeds $500,000$ US dollars. The directed network underlying the plots in the second row keeps the same threshold but introduces the directed nature of the edges. In the first we measure simple degree distribution and in the second, out-degree distribution. The plots show no evidence of a power law. The data underlying the third row is derived from the CPIS network of the core 64 countries. Once again, there is no evidence for a power law in the degree distribution. Similar results were obtained with a number of different thresholds.

Figure C.5: Cumulative degree distributions for network of exposures



The graphs show the probability of a node having degree k or greater. Different colors represent correspond to different years, +2001; ∘2002; ∗2003; ·2004; ×2005; □2006; ◇2007; △2008. 67 reporters vis-à-vis 231 partners.

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