CORPORATE NETWORKS OF INTERNATIONAL INVESTMENT AND TRADE

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

Signed:

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ABSTRACT

This thesis consists of three distinct papers, that each address the globalisation of industries in past decades, specifically the reorganisation of the production process. The structure of production has changed in recent decades; goods are no longer produced completely in one country, rather production is fragmented into several geographically segmented business functions. This thesis argues the need for both alternative methods and data to better explain complex trade and investment, (and therefore production patterns), in the modern global economy.

The first paper advocates the use of network analysis to address the central research themes in the area of international business and economics (IBE). The particular focus is on changes in trade and FDI in light of the fragmentation of the production process. This paper discusses the potential contributions of empirical network analysis to IBE, along with providing a review of the literature that applies network analysis to international trade and investment (such as De Benedictis & Tajoli, 2011). This paper concludes that there is significant potential for the application of advanced network models to address research questions in IBE, especially relating to topics of international trade, investment and production.

The second paper aims at explaining features characterising international trade and investment, (and therefore production), in a high tech sector (the medical and precision instruments industry). The reorganisation of production has resulted in an increase in the importance and level of intra-firm trade (trade amongst affiliated firms), highlighting the need to account for the fact that it is firms – and not countries – that actually trade. This paper applies a multilevel exponential random graph model (as developed by Wang et al, 2013) to investigate the international fragmentation of production by combining both country-level and firm-level networks to capture the interdependencies between international trade and firm level activity. The research question the second paper seeks to answer is: how do the ownership patterns at the firm level contribute in explaining trade amongst countries? The results highlight that the activity of firms and the ties that link them together into business groups significantly shapes trade and investment patterns. In this high tech sector, the analysis reveals that production is characterised by a hierarchical division of labour, with trade concentrated in a handful of nations.

Furthermore, investment motives in this industry are found to be market seeking and strategic asset seeking.

The third paper examines the interplay between the competitiveness of nations and their position in the international trade network in the automotive sector. The reorganisation of the production process has led to increased competition at the international level, with many firms from industrialised nations increasing their level of outsourcing and offshoring of lower value activities to developing countries. Along with the increase in outsourcing activities, many industrialised nations are also now facing increasing competition from emerging economies, who are steadily developing capabilities, in which industrialised nations once held a firm competitive advantage. The third paper makes use of network analysis of the international trade network to analyse the competitive level of countries in the automotive industry, and to answer the research question of to what extent is the competitiveness level of a country determined by its position within the international trade network? The results of the analysis point towards a need for nations to develop the capabilities of domestic suppliers in the automotive sector in order to improve national competitiveness, along with the importance of developing efficient trade ties with competitive nations.

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List of Abbreviations and Acronyms

Abbreviation/Acronym	Name
ALAAM	Auto Logistic Actor Attribute Model
CIP	Competitive Industrial Performance
EMNE	Emerging Market Multinational Enterprise
ERGM	Exponential Random Graph Model
FDI	Foreign Direct Investment
GCI	Global Competitiveness Index
GPN	Global Production Network
GVC	Global Value Chain
IB	International Business
IBE	International Business and Economics
IE	International Economics
IMD	Institute for Management Development
I-O Tables	Input - Output Tables
ITN	International Trade Network
LLL	Linkage, Leverage and Learning
MNE	Multinational Enterprise
OECD	Organisation for Economic Co-operation and Development
OLI	Ownership-Location-Internationalisation
RCA	Revealed Comparative Advantage
RMA	Revealed Import Advantage
RTA	Revealed Trade Advantage
SNA	Social Network Analysis
TiVA Dataset	Trade in Value Added Dataset
TNAM	Temporal Network Autocorrelation Model
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Development Organisation
WEF	World Economic Forum
WIOD	World Input-Output Database
WTO	World Trade Organisation

Overall Introduction

Rapid economic globalisation in past decades has transformed the world economy, including patterns of international trade and investment. Amongst these changes is the restructuring of global supply chains, with production processes "fragmented" into various stages, spread out across the globe (Milberg, 2004).

The reorganisation of production, along with an increase in trade in intermediate goods, presents a challenge to conventional approaches of international trade theory (Jara & Escaith, 2012). Where nations no longer hold comparative advantages in complete goods, the business function level is the more appropriate perspective to analyse production patterns (Grossman & Rossi-Hansberg, 2006). Therefore, the appropriateness of current datasets and levels of analysis in assessing production patterns, given the fragmentation of production, is open for debate (Feenstra et al, 2010; Nielsen et al, 2011; McCleery & DePaolis, 2014).

The transformation of the global economy and the challenges it presents to typical methods of inquiry has resulted in a number of alternative frameworks being developed and utilised, in particular to better understand fragmented production patterns. Amongst the most widely applied is the Global Value Chain (GVC) framework and the related Global Production Network (GPN) approach. GVCs map the linear sequence of activities that bring a product from conception to its end use and beyond (Gereffi et al, 2005). GPNs trace the production process through a set of networks incorporating a range of actors (Coe et al, 2008b).

The GVC approach has become increasingly popular, especially amongst policy makers, as it is able to assess where individual production activities take place within a value chain and the position of nations (Gereffi, 2014). Moreover, it allows to specifically map whether a country is involved in higher value niches or simply low value activities (Gereffi & Sturgeon, 2013). However, it is not without its limitations; the framework is often restricted to a single case study approach, where it focuses only on inter-firm relations, so does not directly account for the role of Foreign Direct Investment (FDI) in the production process. The GPN framework builds on the GVC, moving away from the firm based approach to a framework including a wider range of economic actors configuring production activities in the global economy (Yeung & Coe, 2015). However, similar to the GVC framework, the GPN approach remains chiefly conceptual rather than a quantified empirical method. Therefore, there appears to be a need to build upon these approaches to better explain complex and dynamic production patterns; making use of quantitative tools to establish generalisations regarding global supply chains as they are structured today.

Approaches such as the GVC and GPN frameworks, suggest that the changes in the structure of production have led to a paradigm shift regarding the appropriate perspective to investigate the phenomenon. Within the GPN framework many scholars point towards the use of a relational approach (chiefly in economic geography, amongst them, Dicken et al, 2001; Henderson et al, 2002). Moreover, there has even been a call for a "relational turn" when examining the global economy (Boggs & Rantisi, 2003; Bathelt & Glückler, 2003; Yeung, 2005; Hess & Yeung, 2006).

The GVC and GPN frameworks suggest a relational framework at the ontological level, along with a number of scholars noting the need for a relational approach to better understand the world economy, especially the organisation of production (Jones, 2014). However, extant studies tend to use the relational framework and network term as a metaphor or abstract concept, rather than as an empirical tool. For instance, the network concept is applied as an eclectic term in the GPN context; this conceptualisation of networks has attracted some criticism, given they are often defined at a broad level, where a range of exchanges and entities are included. This ambiguous, (and often imprecise), definition of the network makes empirical operationalisation of the relational approach difficult, where there is a lack of analytical clarity (Sunley, 2008).[1]

Furthermore, the network concept is often applied (again, as a metaphor) to explain changing trade patterns in the global economy. For instance, Athukorala (2014) notes that the rise of global production sharing has led to an increase in trade in intermediate goods, which he refers to as "network trade". The increasing popularity of the network term and relational approaches, at least at the conceptual level, suggests that there is scope to expand the empirical work analysing the reorganisation of production from a network

[1] This is potentially a result of the relational tool that the GPN framework aligns itself with: Actor Network Theory (ANT) rather than Social Network Analysis (SNA), which is a more established method in the empirical context. SNA is better equipped to address research questions empirically, providing a set of statistical tools and advanced methods to identify key actors and structural tendencies in a wide range of networks. However, it is beyond this work to present a critique of ANT, or a comparison of the framework with SNA (see Marshall & Staeheli, 2015 for a brief discussion of the two approaches).

perspective. Where empirical network analysis provides an opportunity to build on current theoretical frameworks suggesting a relational approach.

This project specifically addresses the task of applying empirical network analysis to international trade and investment to understand the fragmentation of production in the modern global economy. The thesis provides an original contribution to the international business and economics field by using advanced techniques in empirical network analysis to explain international production given the transformation of the global economy, and by introducing a novel dataset.

More specifically, it aims to:

1. Explain how a relational framework, more specifically Social Network Analysis (SNA), can complement existing approaches and frameworks to explain the features of the global economy in the world today, including the reorganisation of production.
2. To develop a unique multilevel dataset to overcome the challenges the transformation of the world economy presents to existing macro level data.
3. To apply an advanced network model to the multilevel dataset in order to better inform on the international production, trade and investment patterns characterising an industry.
4. To explore the link between international trade and national competitiveness in a fragmented global supply chain.
5. To operationally explore the extent to which competitiveness is a relational concept.

This thesis addresses these aims through three chapters or papers;[2] these papers may be considered independently, yet address the unified theme of the fragmentation of production from a relational perspective.

The first paper titled "A literature review of the application of network analysis to international trade and investment" is presented after this introduction, providing a literature review. This is then followed by the second paper, "A multilevel network analysis of the international fragmentation of production in a high tech industry". The third paper is then presented, "The fragmentation of production and the competitiveness

[2] For consistency, throughout the thesis each chapter, paper or essay is referred to as 'paper'.

of nations in the automotive sector – a network approach". Finally, an overarching conclusion is provided, noting the key findings from the three papers and avenues for future research.

The first paper examines the contribution that network analysis has made to international trade and outlines the further possible contributions of the application of the most recent developments in network analysis to better understand how production is organised today. It introduces a set of stylised facts characterising the changes to the global economy in recent decades, amongst them the fragmentation of production. The paper then provides a survey of methods and approaches in the standard international business and economics literature to consider these changes. It provides a review of the extant literature applying network analysis to key themes pertaining to the stylised facts identified; in particular, those analysing international trade and investment patterns.

Furthermore, it outlines where network analysis can make further contributions, identifying potential gaps in the literature; towards the end, the value of advanced network models in addressing research questions associated with the transformation of the global economy is also discussed.

In terms of explaining production, Ietto-Gillies (2000) notes the need to better incorporate the role of the Multinational Enterprises (MNEs) in theories of international trade, and to clarify the relationship between international trade and production. The second paper contributes to this discussion, specifically on whether current datasets and methods can explain fragmented production patterns; it presents an empirical investigation which combines in an innovative way two secondary datasets at the country and firm level. Advanced network analysis techniques can further help in this direction, allowing to examine multilevel phenomena, examining the interplay between business group structure at the micro level, their investment decisions (the meso level) and international trade at the macro level.

Whilst there have been a number of studies examining international trade networks, few have made use of advanced network models. In addition, all identified studies have analysed trade networks in isolation from ownership networks. Such approach, however, does not account for the fact that it is firms – and not countries – that actually trade, with an average of 30% of all exports accounted for by intra-firm trade (UNCTAD, 2013). This paper applies a multilevel exponential random graph model (as developed by Wang et al, 2013) to investigate the international fragmentation of production by combining both the country-level and the firm-level networks.

Paper three presents a way to assess the competitiveness or performance of nations utilising a longitudinal network model. This paper provides a relational approach to consider the competitiveness of nations in light of the disintegration of production. The concept of comparative advantage of nations was formulated as bilateral, dyadic. It is recognised, however, that international trade is a complex web of interrelated, non-independent relationships. This means that trade between two countries will also depend on the trade each has with all other countries. This subsequently distorts the (bilateral) concept of comparative advantage; alternatively, the network concept and approach specifically allows to account for higher order effects (i.e. beyond the dyadic level).

The third paper examines the performance of nations, acknowledging that the fragmentation of production has blurred the concept of comparative advantage and its determinants (Baldone et al, 2007). It provides an evaluation of how a nation's position in the international trade network influences its performance over time. This paper takes the product level, examining the performance of nations in separate business functions, rather than aggregated macro sectors.

Overall, this thesis provides a discussion of the fragmentation of production from a relational perspective. It identifies where network analysis has contributed and can contribute further. It then presents two examples of these contributions; one demonstrating an alternative dataset to examine the fragmentation of production, that has both a high level of disaggregation, and accounts for firm affiliation and investment decisions. The second example is an empirical analysis of how position in an international trade network impacts national performance over time.

In this thesis a sectoral perspective is utilised, with cases from the medical and precision instruments industry, a high value sector (the second paper) and the automotive sector, a medium to high tech sector (the third paper). A sectoral perspective is needed as economic conditions can vary drastically across industries, therefore any policy implications identified must be sensitive to industry differences (Sturgeon & Memedovic, 2011). Where any policy recommendations made should be tailored to the appropriate (sector) level of analysis (Pietrobelli & Staritz, 2013; BIS, 2012b).

I - A Literature Review of the Application of Network Analysis to International Trade and Investment

1. Introduction

The globalisation of industries in recent decades has led to a number of fundamental changes in the patterns which characterise the world economy as it is today. A key driver of these changes is an increase in the activity and operations of Multinational Enterprises (MNEs), with international trade and investment patterns closely linked to the organisational form and strategies of MNEs (UNCTAD, 2013).

One could suggest that the transformation of the world economy is a result of four closely related stylised facts. At the heart of these stylised facts is the changing behaviour of MNEs and the subsequent changes to international trade and investment patterns (stylised fact one). These changes in MNE activity have resulted in a rise of FDI activity (stylised fact two). Furthermore, there has been a shift from trade in final goods between unaffiliated entities, to trade amongst parent and affiliate firms (stylised fact three) of intermediate goods (stylised fact four).

These changes in trade and FDI patterns have resulted in a more interconnected world economy, with a need to better understand the interdependencies between entities. Traditional methods and statistical approaches are insufficient to address this challenge; this paper makes the case for network analysis to be used alongside existing techniques and approaches to provide further insights in addressing the phenomena that characterises the world as it is today. Network analysis (see Wasserman & Faust, 1994 for a detailed overview of the field and concepts) allows the specific modelling of interdependencies amongst actors and this paper presents ways in which network analysis can provide new insight in light of existing literature and methodologies.

The paper highlights how international trade and investment literature within international business and economics (IBE) addresses the phenomena identified by the four stylised facts. The empirical methodologies currently applied in their investigation are reviewed, along with where network analysis can make a significant contribution. It also reviews existing studies that have applied network analysis to the study of international trade and FDI to demonstrate avenues for analytical progress.

1.1. Research Questions

This literature review seeks to answer a number of questions, specifically in terms of where network analysis can make a significant contribution in explaining the current patterns of international trade and investment that characterise the global economy.

In order to better explain the phenomena and stylised facts which characterise the world today, there is a need to revisit the current theories and methodologies utilised in IBE, and in particular in the literature examining international trade and FDI. Firstly, there is a need to identify the major themes of IBE, and whether the phenomena (or stylised facts) are sufficiently captured in the research agenda. It is also necessary to consider whether extant theories and methods are still helpful in understanding the changes to the global economy. In order to address this question, two strands of literature that investigate the patterns of international trade, FDI and the organisation of production from different perspectives are analysed. The first strand is a subset of international economics (IE) literature, primarily focused on macro patterns of international trade and investment. The second strand of literature is from international business (IB), which focuses on the micro aspects and primarily investigates international investment trends and patterns through the internationalisation decisions of MNEs.

This provides the opportunity to assess the empirical approaches investigating these areas and provide an overview of where a network analysis approach can offer a contribution to the field. Therefore, this paper asks the following research questions:

1. Are the stylised facts reflected in the International Economics (IE) literature?
2. Are the stylised facts reflected in the International Business (IB) literature?
3. How have these been so far investigated?
4. What can network analysis contribute to extant approaches and methodologies?

Research questions one and two are addressed through a combination of a thematic survey and citation analysis of relevant journals in international business and economics over the last decade. This identifies what phenomena are being pursued in the field and whether it captures the stylised facts characterising the changes to the global economy. The thematic survey and citation analysis also provide an outline of the typical approaches in addressing research questions pertaining to these areas, therefore answers the third research question.

This is then followed by a literature review of the work that applies network analysis to investigate the phenomena on the IBE research agenda, and highlights the value, contributions and insights that a network approach can provide (addressing research question four).

1.2. Contribution

This work contributes to the literature considering international trade and investment, identifying the typical methods and techniques to consider these topics and related areas. It then provides a framework to complement these approaches and to better analyse these complex phenomena: network analysis.

The literature review points to an increased need to adopt a systemic and relational perspective in analysing patterns of trade and FDI, along with MNE's organisation of production activities. This paper provides a discussion of where network analysis can make a significant contribution in analysing the interdependencies characterising the global economy.

1.3. Paper Structure

The paper is structured as follows, with section two elaborating on the stylised facts noted in the introduction and then goes on to identify the emerging themes in IBE through the use of a citation analysis and thematic survey. Section three provides an overview of traditional empirical approaches for the emerging themes and presents the extant literature making use of network analysis to consider these topics.

The final part of the paper looks at recent methodological developments in network analysis which allow to better capture complex phenomena. For instance, the complexity of the international organisation of production may be better explained though advanced multilevel network models, which combine the analysis at the micro level (firm locational choices, traditionally investigated in IB) with the analysis at the macro level (international trade flows among countries, traditionally investigated in IE).

2. A Survey of the International Business and Economics Literature

As noted in the introduction, in recent decades the global economy has undergone a transformation, which can be outlined by four related stylised facts.

Stylised Fact One: There has been an increase in the international activity of MNEs and a change in their organisational form.

MNEs account for the lion's share of economic activity and their sales have risen in recent years (Navaretti et al, 2002; Helpman et al, 2004; Antràs & Yeaple, 2013; Helpman, 2014). As noted by Helpman (2006: 626) the organisational change of MNEs has driven the "transformation of the world economy". These changes include a reorganisation of their production activities; no longer manufacturing a product in a single location, rather having a disintegrated production process, making use of international sourcing strategies (including both offshoring and outsourcing) in order to coordinate their global supply chain.

Outsourcing has become an important characteristic defining the global economy and Grossman & Helpman (2005: 136) conclude that "the outsourcing of intermediate goods and business services is one of the most rapidly growing components of international trade."

Along with a change in the international activity and organisational form of MNEs, a new breed of MNE has also arisen in recent years: emerging market MNEs (EMNEs). The rise of these EMNEs is one of the more recent and important aspects of globalisation, with an increasing economic significance, contributing to a high level of FDI activity (Amighini et al, 2009; Hoskisson et al, 2013).

Stylised Fact Two: There has been an increase in FDI

These changes in the organisational form and increased global activity of MNEs has resulted in fundamental changes in the overall patterns of both FDI and international trade (Milner, 2014). One change is that there has been an increase in FDI flows in recent times, which has not only increased in quantity, there has also been an increase in the complexity of FDI patterns, with the traditional classifications of horizontal and vertical FDI becoming less meaningful in the empirical context (Helpman, 2006). FDI has become further interconnected with patterns of international trade, with around 80% of world trade linked to the production networks and locational choices of MNEs (UNCTAD, 2013).

In more recent years, a large portion of FDI can be attributed to outward FDI from emerging markets, reflecting the rise of EMNEs in the global economy. This has included a 17% increase in the value of annouced greenfield FDI in 2013, along with a strong role as acquirers, with a rise of 36% in cross border Merger & Acquication (M&A) activity (UNCTAD, 2014).

These changes in FDI patterns and the increase in FDI activity from emerging markets emphaises a need to understand the competitive and strategic locational decisions of firms and business groups, in order to better explain patterns of FDI, and how they vary across both regions and industries.

Stylised Fact Three: Intra-firm trade is a large share of world trade

Along with a rise in FDI, international trade patterns and composition has changed; international trade is no longer dominated by trade in final goods between unaffiliated parties. Rather a large proportion of world trade is characterised as intra-firm trade, (a stylised fact identified by Lanz & Miroudot, 2011). Intra-firm trade refers to the flow of goods (or services) between a parent and affiliate firm. The reorganisation and coordination of MNE production processes into geographically segmented production sites has substantially increased the importance of intra-firm trade in the world today (Lanz & Miroudot, 2011; Antràs, 2014).

Although intra-firm trade statistics are scarce and vary across industries, available evidence does point to an increase in the share of intra-firm trade of total trade. For instance, a number of studies have considered patterns of intra-firm trade in the US (Zeile, 2003; Borga & Zeile, 2004; Bernard et al, 2009), with Bjelic et al (2012) noting that in 2009, 48% of US imported goods and 30% of US exports were intra-firm trade flows.

Stylised Fact Four: There has been a rise in trade of intermediate goods

As previously stated, the increase in international MNE activity and the subsequent rise in FDI flows has led to a change in both the amount and composition of international trade. With MNEs extending their involvement in international activities, incorporating international sourcing strategies into their production process has resulted in an increase in trade of intermediate goods (De Backer & Yamano, 2012).

Along with change in trade composition and value at the aggregated level, the trading profiles of individual nations have changed over the past decade. In particular, the trading patterns of low and middle income economies have gained prominence in their contribution to global GDP and FDI activity (Hoskisson et al, 2013).

Given the transformation of the global economy, the first set of questions this paper seeks to answer is to what extent are the changes reflected in the research undertaken in IBE? A second question would be how have these changes been investigated? In order to address the first set of questions a thematic survey of relevant international economics journals coupled with a citation analysis of leading international business journals was undertaken.[3]

The bibliographic data used in the citation analysis and thematic survey was extracted from Thomson Reuters Web of Science. Whilst not an all-inclusive collection, the extensive coverage it provides is sufficient for the aims of this paper in order to identify the key themes driving the research agenda in IBE.[4] For further details on the thematic survey and citation analysis search criteria and output, see Appendix A and B respectively. The results presented in the appendix indicate that the stylised facts are captured in the literature, (to an extent) though numerous frameworks and approaches.

The stylised facts represent a set of intertwined and closely related phenomena. The results of the citation analysis and thematic survey highlight that the four stylised facts are not studied in isolation or in individual strands of the literature. Rather they are overlapping with the transformations of the global economy crossing many sub strands of the IBE literature, with interdisciplinary characteristics.

For instance, the international activity and organisational form of MNEs (stylised fact one) is addressed from different perspectives. International sourcing patterns are considered in streams of literature ranging from the micro firm level perspective of a firms' decision to conduct FDI or export, to complex macro topics involving the changing trade patterns of nations.

[3] A thematic survey rather than a citation analysis was undertaken for the international economics journals for a number of reasons. Firstly, the international economics journals, whilst more relevant, do not hold the high ranking positions, (especially when compared to the leading international business journals), and therefore their citation impact is comparable lower. Furthermore, as the search undertaken is more defined and focused, the output is more manageable, allowing for a more thorough examination of the work considered in international economics pertaining to international trade and investment.

[4] For a critique of Web of Science citation data see Kapeller (2010).

The citation analysis and thematic survey indicate that to understand phenomena such as intra-firm trade and intermediate goods trade, it is not sufficient to only consider the literature on international trade. The literature on the fragmentation of production associates these changes to the reorganisation of the global supply chain in various industrial settings. In turn, these phenomena are examined in relation to the regionalisation versus globalisation debate (for instance Athukorala, 2011, examining trade patterns within East Asia).

Below are the five themes identified through the citation analysis and the thematic survey under which the stylised facts previously exposed are investigated.

1. MNE behaviour
2. International trade
3. FDI
4. Fragmentation of production
5. Regionalisation versus globalisation

The first three strands (or themes) clearly capture the changes to the global economy: MNE behaviour, changes in international trade and changes in FDI patterns. The next relates to the fragmentation of production, which is applied as an encompassing term, capturing the reorganisation of production, increased level of offshoring and outsourcing activities and changes in the structure of foreign trade. As noted by Helpman (2006), the trends characterising the global economy are closely related to the growing fragmentation of production, in which MNEs are playing an increasingly important role. The fragmentation of production currently holds key positions in the international trade and FDI research agenda and is considered to be an important research topic by a number of international organisations (UNCTAD, 2013). Furthermore, the regionalisation versus globalisation debate highly overlaps with the work tackling the stylised facts and must be considered further in light of the changes to the global economy and the disintegration of production; therefore, is considered the fifth key theme driving the research agenda in IBE

2.1. Emerging Themes in International Economics

Within the IE literature, the stylised facts, (along with a range of other topics), are considered from a macro perspective. The level of analysis of the 165 IE articles surveyed was chiefly the country level, suggesting that within IE, the nation state is still the focal lens for addressing research questions, contrasting to IB, where the level of analysis is often the multinational firm.

The thematic survey results (which can be found in Table 1 in Appendix A) indicate a number of topics related to international sourcing, offshoring, slicing of the production chain and intra-firm trade, suggesting that this literature acknowledges that the transformation of the global economy is closely associated with increased complexity in production patterns.

2.2. Emerging Themes in International Business

The citation analysis results can be found in Table 2 in Appendix B, and highlights the differences between the IB approach and the IE approach in addressing the stylised facts.

The IB literature chiefly takes a micro level perspective in addressing the stylised facts. The most cited articles reveal that the MNE remains the focal unit of analysis. The globalisation of industries and consequent changes in terms of MNE's organisational form with a rise in more complex ownership and investment patterns has been recognised as a key research area to consider within the field of IB (Buckley & Ghauri, 2004). Furthermore, the internationalisation strategies of EMNEs has taken a more important place in the IB research agenda, reflecting their rise and increased importance in the global economy (Peng et al, 2008; Luo & Tung, 2007).

A relevant aspect that emerged from the citation analysis is that many of the influential works in IB are urging scholars to pursue a relational approach at least at the conceptual level. For instance, Griffith et al (2008) suggest that there is a need to reconsider the unit of analysis in IB when addressing research questions pertaining to global industry and strategy; noting that there is a need to capture performance at the network level rather than the individual firm level. Johanson & Vahlne (2009: 1411) argue that a business network model is required to better understand the internationalisation process. They note that "the business environment should be viewed as a web of relationships, a network, rather than a neoclassical market with many independent suppliers and customers."

This paper suggests that networks should not only be applied conceptually; that there is scope for empirical network analysis, which can contribute to shed light on the stylised facts earlier discussed.

2.3. IB & IE – A brief comparison

Overall, the results from the citation analysis and thematic survey suggest that research in IBE reflects the changes to the global economy discussed at the beginning of this section. Although there is overlap between the themes addressed in IB and IE, the methodologies and frameworks of these fields differ, with IB focused on explaining micro level patterns, with the firm at the heart of the analysis; whereas IE chiefly takes a macro approach, examining trade and investment patterns of the nation state. IB addresses research questions primarily through qualitative analysis, whilst IE takes a quantitative approach, making use of statistical models (such as Helpman et al, 2004).

Whilst the qualitative analysis is not constrained by rigid assumptions that often characterise quantitative analysis (e.g. the assumption of independence of cases in regression analysis); this approach is often case specific, and is limited in the generalisations that can be made. A quantitative analysis would allow for overall patterns and tendencies to be identified, but this is often reduced to an over-simplified analysis of a complex phenomenon. This suggests the need for a more comprehensive approach, integrating the international economics literature with that of international business and economic sociology, presenting an interdisciplinary framework to address the stylised facts.

An element shared by both the IB and the IE literature is an urge to adopt a more relational perspective. A relational perspective is urged in the IB literature, where the network metaphor is frequently applied (such as Johanson & Vahlne, 2009; Griffith et al, 2008), yet empirical network analysis is rarely pursued. Similarly in economics, the link between trade and networks is often discussed (amongst them Rauch, 2001). For example, in his review of the interdisciplinary approaches to the fragmentation of production, Dallas (2014b) notes that a network perspective could provide further insight and capture the interdependent nature of firms involved in the production process. He also recognises that a number of streams of literature, (such as the global commodity chain and global production networks), refer to networks conceptually and suggests that there should be a "more systematic application of formal social network analysis methodologies" (2014:

18). Jackson (2014) also urges a network perspective in a number of economic settings. He argues that networks aid in better understanding economic phenomena, and that neglecting these interactions can result in a number of important factors being missed, emphasising that decisions by individuals are shaped and made in the context of their network interactions.

Even though a large number of studies in international business and economics use the network term in a metaphorical sense, there are limited attempts to use models which specifically recognise the interdependencies of interconnected entities. The implementation of network theory and methodology can allow to go further, enabling to visualise, describe, explain and model economic and business relations characterised by interdependencies. In the context of international trade and production, Amighini & Gorgoni (2014) provide a case for why network analysis should be used. They acknowledge standard statistical techniques fail to capture the interdependences that characterise international trade as it is today; especially in light of the fragmentation of production. They emphasise that standard approaches only consider first order bilateral effects, and neglect the indirect, higher order effects; this is an area in which network analysis can clearly contribute, as it specifically assumes dependency between observations.

To conclude, the survey and citation analysis identified five strands in the IBE literature which investigates the transformation of the global economy exposed at the beginning of this section. In order to establish where network analysis can contribute in explaining the stylised facts and the changes to the global economy, in the next section of the paper these five strands of literature will be examined separately, discussing for each what network analysis has to contribute.

3. A review of the traditional and network literature in the five IBE areas identified

This section aims to address the third and fourth research questions presented by this paper, more specifically, how have the research areas identified by the analysis of the IBE literature been investigated so far, and what can network analysis add?

Each subsection discusses one of the five research topics, and consists of two parts (a. and b.), where the first provides an overview of how the research topic has been approached so far (answering the third research question). The second part then provides an overview of extant studies utilising network analysis to investigate these research areas, arguing the value of the application of network analysis (answering the fourth research question).[5]

3.1a Multinational Enterprises: Traditional Approaches

The nature, organisation and behaviour of MNEs and their relationship to value chain activities is an area of fundamental importance to the IB research agenda. The most extensive theory on MNE activity is the eclectic paradigm as introduced by Dunning (2013), and has been altered and extended in a number of ways since its original introduction. One of the fundamental questions is why a firm would choose to serve a foreign market through an affiliate, rather than exports? This question has primarily been answered through the examination of a firm's intangible assets, making use of the Ownership-Location-Internationalisation (OLI) paradigm.[6]

This eclectic paradigm suggests that FDI patterns of a nation can be explained by the OLI advantages of its enterprises relative to those of other nations (Dunning, 2013). A criticism of this framework's classification identified by Yeaple (2013), is that it is too rigid, as a firm may hold one of the advantages in a certain region, which could be considered a disadvantage in another.

There is a vast stream of literature surrounding MNE activity and their internationalisation strategies, along with their place in the production process. In terms of how these multinational groups organise their supply chain activities, a useful approach is the one that considers MNEs as business groups, making use of the definition provided by Altomonte & Rungi (2013: 1). The authors define business groups as "network-like forms of hierarchical organization between legally autonomous firms spanning both within and across national borders". According to this definition, MNEs can be classified as business groups because their subsidiaries are legally separate and yet are managed by

[5] The exception is section 3.3. which is not split into two, given the limited application of network analysis to FDI.

[6] The ownership advantage refers to the extent to which an enterprise owns or possesses assets which foreign firms do not have access to. The location specific asset determines the extent to which a firm can locate its production facilities outside of the home nation. The internationalisation specific advantage assesses whether an enterprise should internationalise or licence a foreign enterprise.

a common parent firm. This approach suggests that an analysis of an ownership network can prove to be useful in an investigation of the behaviour of MNEs.

One of the emerging themes in the literature on MNEs is the behaviour of EMNEs and their FDI patterns (see Amighini et al, 2009 for a review of this literature). The rise of these EMNEs has generated a debate into whether the typical OLI theory of multinationals is equipped to explain the behaviour and characteristics of EMNEs (Guillén & García-Canal, 2009; Narula, 2012; Cuervo-Cazurra, 2012). The main conclusion which emerges from this debate is that there is a need for a new theory when considering EMNEs; that the OLI paradigm's prerequisites for FDI are misaligned with the observed behaviour of EMNEs (Hennart, 2012). For instance, within the OLI framework the ownership advantage suggests that a firm is required to possess a number of intangible assets which it is able to exploit in order to undertake FDI. Therefore, this approach fails to explain the investment patterns of EMNEs that do not possess these assets. The OLI approach also fails to explain strategic investments, which improve rather than exploit a firms' intangible assets (Amighini et al, 2009).

Amighini et al (2014) provide an alternative approach to explain EMNE behaviour, making use of the business group framework. They acknowledge that investment decisions of EMNEs are not made in isolation of other firms belonging to the multinational or business group, whereas standard approaches only consider the perspective of the investing firm from emerging markets, neglecting the behaviour of the remainder of the group. Amighini et al (2014) further note that the business group framework can be utilised to consider three research areas. Firstly, capturing and assessing the complexity of business group structure. Secondly, to account for how group level structure is connected to value chain activities. Finally, how business group strategy and organisation affect performance and productivity.

3.1b Multinational Enterprise: How can network analysis contribute?

As a business group can be easily conceptualised as a network, addressing MNE behaviour in terms of network analysis appears natural. Scholars have previously conceptualised an MNE as a network of firms; an early instance is that of Ghoshal & Bartlett (1990) who conceptualised a multinational enterprise as an inter-organisational network. They suggest that the configuration of these enterprises goes beyond the simple dyadic relationship of parent and affiliate, and should be considered at the group level.

These early attempts to approach MNEs from a network perspective, however, only use the network as a metaphorical concept, and do not apply network analysis to capture the interdependencies characterising these networks.

When considering EMNEs, a network approach provides scope to better explain their investment decisions and behaviour. Mathews (2006a) introduces an alternative theoretical approach to analyse EMNEs, which considers the global economy as a web of inter-firm linkages. He presents a framework consisting of three components: linkage, leverage and learning (LLL). The linkages element captures an EMNE's ability to identify and compensate for gaps (or limited ownership assets) via an extensive network. Leverage refers to the EMNEs ability to exploit unique comparative advantages. The third, and perhaps most novel aspect, with respect to EMNEs, is the learning element, capturing whether an EMNE's investment is motivated by a need to learn and strengthen capabilities (Peng, 2012).[7] Therefore, an empirical network analysis of emerging multinational groups can contribute in operationalising and extending this theoretical framework. The alternative approach of the LLL framework has generated some debate in IB over its validity, along with whether it is in a direct contest with the OLI paradigm (Narula, 2006). However, many recognise that the LLL paradigm simply complements the OLI, providing another tool to consider the patterns of challenger firms from emerging markets (Dunning, 2006; Mathews, 2006b).

Network analysis provides a way to represent business groups, expressing MNEs (either from developed nations or emerging markets) as a network of firms linked by ownership. Ownership networks reflect the close, persistent relationships between legally separate entities which characterise a business group. Network analysis of firms tied by ownership links is not new, and a range of studies have approached research questions using ownership networks, primarily addressing issues such as corporate control and how the network structure can influence corporate governance and behaviour (Piccardi et al, 2010; Kogut, 2012; Vitali et al, 2011).

The research questions dealt with by the literature on ownership networks, however, differ from those considered by standard MNE and business group literature. For instance, the literature examining business groups focuses on examining the presence of business

[7] Learning has been long identified as a key driver of dynamic capabilities within MNEs (Teece & Pisano, 1994; Teece et al, 1997).

groups in emerging economies (Leff, 1978; Carney et al, 2011; Cuervo-Cazurra, 2006), along with a debate in regards to whether these business groups are paragons or parasites (Khanna & Yafeh, 2007).

There is a large amount of research conducted by physicists that analyse the ownership network, chiefly examining these networks as they often represent a large complex system. For instance, Battiston and his colleagues (Vitali et al, 2011; Vitali & Battiston, 2013; Battiston, 2004) have undertaken extensive work on complex networks of international ownership. This research group focuses on issues of corporate control within these networks.

Recent methodological developments in the field of network analysis combined with increasingly rich databases allow the consideration of business and multinational groups through network analysis in order to make inferences in regards to how their organisation has changed over time, along with whether their performance is associated with their business group structure, thus adding value to traditional approaches in the field. Furthermore, a network perspective could also allow to identify strategic decisions of multinational groups, more specifically, how a group enters a region or sector. In the context of business groups, network analysis particularly provides a potentially useful contribution as an alternative approach to analyse the behaviour and investment decisions of EMNEs.

3.2a International Trade: Traditional Approaches

Over the past few decades, a number of trade studies have emphasised the use of the gravity model, which is often considered the standard bearer in the analysis of international trade; Ward et al (2013: 95) state that it has long been the “empirical workhorse for modelling international trade” and that it is a very successful empirical model in predicting bilateral trade flows. The model has been extended and altered to answer a number of specific questions within the discipline, including the modelling of intermediate inputs and intra-firm trade (Bardhan & Jaffee, 2004). The gravity model is an econometric model reminiscent of Newton's law of universal gravitation; where the volume of trade between two nations is positively related to their economic size, and negatively to their distance (Anderson, 2010). While its virtue is parsimoniousness, perhaps the most serious disadvantage of the gravity model is that it assumes that dyadic trade is independent, ignoring multilateral dependencies. With products no longer being manufactured in a single location and increasingly made of parts produced in multiple nations, the independence assumption becomes too strong (Ward et al, 2013).

Anderson & van Wincoop (2004) recognise that the gravity model only captures bilateral trade in a multilateral world, and attempt to compensate for this by introducing a multilateral resistance term. Multilateral resistance is where the economic distance between two nations is not only based on the bilateral distance but also the weighted average of economic distance to all other trading partners. Despite the fact that the gravity model has been extended to account for this limitation through the use of multilateral resistance it still fails to capture different aspects and effects of these interdependencies (Kareem et al, 2014).[8] Where the specification of the multilateral resistance term simply relaxes multilateral dependence, instead focusing on bilateral dependence; therefore this does not capture the full interdependence of trade in the (multilateral) global economy as indicated by trade theory (Behrens et al, 2012; Koch & LeSage, 2015).

Bernard et al (2006) acknowledge that in the analysis of international trade, the role of firms, and in particular MNEs, is often omitted. In line with New Trade Theory, within economic models of international trade, the roles of firms are primarily addressed through the use of heterogeneous firm models. These models explain both the interaction between firm heterogeneity, trade and the productivity advantage of exporters (Bernard et al, 2006). This allows the models to capture the uneven distribution of trade, and that trade is concentrated within a small number of firms. Although these theories explain patterns of productivity growth and trade through their inclusion of heterogeneous firms, much remains unexplained, such as an explicit consideration of the boundaries of firms, including their production decisions.

The next section reviews extant studies applying network analysis to international trade to show how this methodology can capture interdependencies better than methods based on dyadic interaction.

3.2b International Trade and Network Analysis

The literature making use of network analysis to study international trade crosses a number of disciplines, ranging from statistical approaches to the theoretical use of the network framework.

[8] For a full overview of the gravity model and its variants see Head and Mayer (2013).

One stream of literature focuses on making use of network analysis to complement the gravity equation methodology, where it can provide additional insights into the structure of trade; this has been an approach pursued in addressing a number of research questions. Min Zhou has frequently used this approach in addressing research questions concerning political, cultural and geographic proximity of nations, and how this impacts trade between the different partitions of the World System – the core and the periphery (Zhou, 2013). Zhou (2011) approaches the issue of homophily, suggesting geographic and cultural proximity promote trade, and testing whether globalisation has weakened homophily over time. The result from this analysis shows that geography and cultural similarity do matter, and that the importance of these effects has increased over time, especially in the case of intermediate inputs.

Additionally, Magerman et al (2013) recognise the need to include third country effects within the gravity model specification and turn to a network approach in order to achieve this. They implement a gravity model, including a number of network measures to represent concepts such as international competitiveness (out-degree), import openness (in-degree) and potential competition effects (clustering coefficient). From the gravity model analysis, they note that countries that are highly clustered are subject to intense international competition, identifying that regular determinants of international trade remain important and that network effects are more important for larger nations.

Network analysts have contributed in assessing the reliability of the gravity model in network terms, determining the extent to which it can explain higher order features of the international trade network. The international trade network (ITN) is a network of nations linked by trade ties, directed from the exporter nation to the importer. Fagiolo (2010) examines the ITN as generated by gravity model specifications and the residual network, which contains the network characteristics not explained by the gravity model (i.e. the variance that remains unexplained by the gravity model). The primary property which cannot be explained by the gravity specifications, (a characteristic of the residual network), is the power law distribution, reflecting the skewed distribution of trade ties within the network. Dueñas & Fagiolo (2013) build upon this work, comparing the predicted ITN to the observed, they conclude that whilst the gravity model is good at estimating the presence of a link, it is unable to explain higher order effects (such as triads or clustering), or why links persist over time.

A further stream of literature making use of network analysis to international trade is that of econophysics, with a large number of papers in this area. However, as in other areas of econophysics, there is much debate in terms of the extent to which they contribute in explaining economic phenomena, rather focusing on statistical and – in the case of network analysis – topological properties (Gallegati et al, 2006).[9]

The work of econophysicists primarily focuses on testing statistical methods (such as null and fitness models) on a complex network, often using the ITN as a setting, as it has a scale free and complex structure, and data is readily available. The analysis of econophysicists often does not go any further than commenting on the structure and topology, rather than contributing to explanation of the underlying economic phenomena (amongst them Fagiolo et al, 2008; Serrano et al, 2007). As described by Dueñas & Fagiolo (2013: 157), a large quantity of this literature has been "focusing on a purely empirical quest for statistical properties."

For instance, Ermann & Shepelyansky (2011) use the ITN to test a ranking algorithm; demonstrating that there is a correlation between ranking trade flows by imports and ranking them through the use of the page rank algorithm. This result is interesting, and demonstrates that this ranking technique is somewhat robust and could be applied to other networks. However, it does not contribute a great deal in explaining international trade, or why certain nations hold a particular position in the trade network.

The application of fitness models is a notable technique applied by econophysicists in analysing complex networks, and specifically the ITN. A fitness network model captures the probability that two nodes are connected as a function of a particular nodal attribute, in the case of international trade this is GDP (Garlaschelli & Loffredo, 2005). Garlaschelli et al (2007) and Garlaschelli & Loffredo (2004) make use of fitness models in order to show that there is an interaction between the ITN topology and GDP, yet their work does not go beyond identifying the association, or linking conclusions to existing literature on international trade and GDP.

In the field of network analysis, there is often a degree of friction between the work of social network analysts and physicists, with a separation between the two, including at times the use different terms to refer to the same concept. There is tendency for the work

[9] Topological properties refer to characteristics of the network used to describe the arrangement of both nodes and ties in the system.

of physicists to be often unaware of previous studies conducted by social network analysts, and with network analysts reluctant to engage with the material of physicists (Scott, 2011; Freeman, 2011). These tendencies are also observed within the area of the international trade network, with a tendency for econophysics' literature to be written in isolation of standard SNA methods and approaches, and to neglect other network analysis of international trade, such as that of Luca De Benedictis and colleagues (De Benedictis & Tajoli, 2011; Abbate et al, 2012). Nevertheless, the work of econophysicists provides a set of general results, along with the behaviour of country specific attributes that (potentially) complement the other studies of the ITN in terms of analysis and modelling strategies.

An area of early application of network analysis to international trade as a tool for economic analysis is that of World Systems Theory, which conceptualises national economic development and trade within a core-periphery structure (Wallerstein, 1987). Snyder & Kick (1979) applied formal blockmodelling techniques to empirically classify countries within the world systems core-periphery concept.[10] Smith & White (1992) then built upon the work of Snyder & Kick, making use of different blockmodelling techniques to reassess the empirical status of the world system; identifying the rise of exporters from newly industrialised economies.

Positional analysis, utilising structural equivalence and blockmodelling techniques can be further utilised in examining the roles of emerging economies in international trade and investment. The structural equivalence concept could be applied in order to examine groups of nations in similar positions, and whether in terms of trade, these emerging economies are moving into trading positions previously strongly held by Western nations.

Furthermore, this positional analysis approach could be utilised to consider issues pertaining to macroeconomic phenomena, for instance, analysing the major changes in China's international trade and integration patterns; perhaps further investigating the trends related to its development strategy. Reyes et al (2008, 2010) make use of network analysis to provide an alternative to the trade to GDP ratio to investigate trade openness. They specifically analyse the integration of East Asian and Latin American nations,

[10] Blockmodelling involves identifying structurally equivalent positions, where two actors have identical ties to all others in the network. A more relaxed version of structural equivalence is regular equivalence, which instead captures the extent to which two actors hold the same position in the network, that is they have identical ties to equivalent actors in the network (Wasserman & Faust, 1994).

concluding that the high performance of Asian economies is associated with increased economic integration. Further macroeconomics topics addressed through the use of network analysis include an investigation of how trade enhances the growth of a country in relation to its position in the ITN (Kali et al, 2007) and the examination of the spread of shock originating from financial crisis within the ITN (Kali & Reyes, 2010).

Another research area still underexplored and where network analysis could further contribute is the one aiming to explore how trade patterns and the role of nations differ across industries, given the increasing empirical evidence pointing in this direction (as exemplified by De Benedictis & Tajoli, 2011; De Benedictis et al, 2014).

3.3. FDI

FDI is a key focus within the field of IB, which focuses on the topic from the firm level perspective. Yet the majority of available data on the topic is limited to the country level. Blonigen & Piger (2011) note a lack of consensus on how to model bilateral FDI flows. In terms of standard approaches, empirical studies include the gravity model and MNE general equilibrium models, such as those introduced by Helpman (1984). Early MNE general equilibrium theory suggested that FDIs were motivated by either horizontal or vertical growth considerations. Since then, much work has been undertaken to reveal more complex motivations for FDI, such as the part they play in the international fragmentation of the production process. Blonigen (2005) highlights a key weakness of the MNE general equilibrium theory, specifically that it assumes the bilateral relationship of a parent investing in a foreign affiliate is independent of the parents' other investments (and bilateral ties).

The limitations of the gravity model in the case of FDIs is even more apparent than in the context of international trade, as a firm's investment decisions are not made in isolation of each other, rather they are highly interdependent, forming part of a long-term business strategy (Baltagi et al, 2008).

Chen & Chen (1998) suggest that a network perspective represents a different way of considering FDI and business group activities. They provide an early example of conceptualising FDI flows as a network, noting that the network linkages of a business or multinational group (both internal and external) drive and facilitate the locational decisions of FDI.

Although network analysis provides a natural way to examine FDI, there are relatively few studies examining it with a network analysis framework, and even fewer are those oriented toward explaining the network structure of FDI flows and their drivers. For instance, Koskinen & Lomi (2013) make use of FDI data, using this network to test a variant of the longitudinal exponential random graph model that they have developed, focusing more on the statistical side of the model, rather than on the outcomes in terms of explaining the dynamics of FDI. A further study considering a network of FDI is that of De Masi et al (2013) based on a relational dataset of Italian firms linked to countries. However, they project this investor-nation network into firm-to-firm and country-to-country networks. This results in a loss of information, and is debatable whether a network of firms linked by shared location and a network of nations linked by the same firms investing in them, can explain more complex investment strategies pursued by firms today.

One particular explanation for the lack of network studies examining research areas pertaining to FDI is the lack of appropriate data; unlike international trade, reliable FDI data is unavailable for many nations. There is a lack of complete cross country datasets, especially when compared to the case of international trade, where UN Comtrade provides freely available data, with extensive coverage over several decades, highly disaggregated, which is presented in a format that can be easily converted into relational data.

However, as more extensive and reliable data becomes increasingly available, there is much scope for the use of network analysis in order to capture the interdependent nature of FDI. An area of study which seems particularly promising – but also very challenging in terms of data requirements – is one attempting to explain FDI through firm level data, rather than country level data. For instance, the FDi Markets database provides the opportunity to examine various cross border investments, providing both firm and country level data, which can be utilised to map sectoral and national investment networks.

3.4a Fragmentation of Production: Traditional Approaches

There have been various attempts to extend traditional models of international trade to include the phenomenon of the fragmentation of production. For example, many scholars have investigated the nature of factor price differentials and their effects within the context of the fragmentation of production, amongst them Venables (1999), Jones & Kierzkowski (2001), Deardorff (2001a, 2001b) and Kohler (2004).

Sturgeon et al (2008: 298) note, however, that whilst classic concepts, such as comparative advantage, are useful because of their predictive power, they have become "too thin and stylized" in understanding the complexity of production today. They argue that the Global Value Chain (GVC) concept and approach provides a more "pragmatic and useful framework" to analyse these phenomena. The GVC framework considers the linear sequence of activities that bring a product from its conception to end use and beyond, acknowledging that these activities may be spread across a wide geographic space (Gereffi et al, 2005). GVCs provide one of the fundamental approaches in considering research questions pertaining to the international fragmentation of production (Sturgeon, 2008; Gereffi, 2001; OECD, 2012).

The GVC approach provides a number of insights to international business, specifically providing an approach to examine how MNEs interact with suppliers and how they manage their production activities. The GVC approach complements the IB literature, as it is equipped to supplement existing frameworks examining why firms internationalise, and the organisational form of these global firms (De Marchi et al, 2014). Although closely intertwined with the IB literature, Amador & Cabral (2014) note that there is a gap in the literature, specifically the link between the GVC approach and macroeconomics. This suggests that the IE literature could further benefit from the integration of the GVC approach. For instance, the development and application of the gravity approach is well documented in international trade theory, however there is the possibility to investigate the impact of gravity on GVC dynamics.

Whilst GVCs are clearly a useful analytical tool in the investigation of the organisation of production across borders, the majority of the empirical studies utilise case studies, (such as Linden et al, 2009; Dedrick et al, 2010), rather than quantitative methods, so the conclusions which can be made are often case specific rather than relating to the overall patterns of production and trade (Fine, 2013). Also, within the literature utilising the GVC framework, the role of FDI is often omitted, along with the nature of parent-subsidiary relationships; as there is often a focus on inter-firm trade and transactions rather than intra-firm (Sturgeon, 2000). Despite these shortcomings, the GVC framework remains a valuable and prominent tool in the study of the international fragmentation of production, with its use well documented in the study of the electronics (Sturgeon & Kawakami, 2010), automotive (Sturgeon et al, 2009; Sturgeon & Biesebroeck, 2011) and apparel industries (Gereffi & Frederick, 2010).

GVC literature has often focused on case studies in empirically mapping a single product's manufacture, and where value lies. However, recently there have been several attempts to explain GVC patterns, and to address questions in terms of value added in a more quantitative manner. For instance, a collaboration between the OECD and the World Trade Organisation (WTO) has resulted in the development of the Trade in Value Added (TiVA) dataset (OECD, 2013). In addition to this there have been a number of efforts to improve input – output datasets, which can be used to map production chains; one is World Input–Output Database (see Dietzenbacher et al, 2013 for details). Baldwin & Lopez-Gonzalez (2015) acknowledge the value of these datasets and recognise that they have been underutilised. However, the limits of these databases must be noted, in terms of industry and country coverage, when compared to that of standard international trade databases.

A further analytical tool available in the study of the disintegration of production is that of Global Production Networks (GPNs), which runs parallel to the GVC concept, sharing many elements, such as, the idea that production is split into interrelated operations. However, the key difference between these two frameworks is that whilst GVCs are sequential linear structures with a focus on governance, GPNs attempt to encompass a wider range of network possibilities, and various other actors in the network, not just firms (Coe et al, 2008a). Coe et al (2008b) note that whilst the GPN concept contains a number of insights from the GVC concept, it provides a multi-actor analysis which reveals a range of characteristics about transnational production. It must also be noted that within this framework, the term network is a metaphor and much of the research on GPNs takes a conceptual approach rather than an empirical. Whilst GVC and GPN are considered separate (yet related) frameworks, the production process is often a combination of the two, with some elements taking on a linear sequence, and others a network (Baldwin & Venables, 2013).

A number of other distinct approaches exist to map the fragmentation of production. One of the most widely applied is the use of highly disaggregated international trade data of intermediate goods. This approach was first conducted by Yeats (2001) and Ng & Yeats

(1999), and has been utilised in a number of empirical studies (amongst them Athukorala & Yamashita, 2006; Türkcan & Ates, 2011).

3.4b Fragmentation of Production: Where can network analysis contribute?

The GVC and GPN approaches emphasise a paradigm shift in the way in which production is organised, with products no longer manufactured in their entirety in a single location. This structural change has strongly increased the economic interdependence amongst countries, and has led policy makers to reconsider areas such as macroeconomics and competitiveness (Amador & Cabral, 2016). Network analysis provides a way in which to investigate this fragmented organisation of production, capturing interdependences empirically; however, there have been a relatively small number of studies which have considered the fragmentation of production through a network analysis framework. Srholec (2006) takes a network approach to consider the topic of fragmentation, making use of UN Comtrade's Broad Economic Classification (BEC) to distinguish between final and intermediate goods, in order to construct a trade network of intermediate inputs. Yet the network analysis here is a rather broad, narrative approach, concluding that this intermediate inputs network is characterised by a core-periphery structure, and that determinants of trade differ between the core and the periphery. Where at the densely connected core of the network, trade is not related to cross country differences in productivity, technology or skills. However, these cross country differences are noted to play an important role in determining trade between the nations belonging to the core and those in the periphery, along with intra-periphery trade.

Amighini & Gorgoni (2014) examine the reorganisation of production within the automotive industry. They use network visualisation tools and apply network analysis measures to highly disaggregated, directed and valued trade data, in order to examine the structure of the trade network for individual component categories. They highlight that within the automotive sector, the participation and changing role of emerging economies in production activities, (primarily as key suppliers), has caused a shift in the way production is organised. Their study highlights the value of considering a high level of disaggregation and examining components rather than final products trade to make sense of the fragmentation of production and current patterns of international trade. Their work provides a clear example of how the structure of international trade can differ not only across industries, but also at the component level. In addition, their analysis of brokerage provides insights on the degree of power that actors may possess in the network despite not being at the core. In fact, consideration of the structural position countries occupy in the network allows to expand the notion of power beyond that of individual attributes (such as GDP) and onto one which is relational.

Blázquez & González-Díaz (2015) provide an empirical network analysis of the automotive sector in a similar way, examining a trade network of parts and components and a network of final goods. They undertake a descriptive analysis of the networks for 1996 - 2009, where they note consistent patterns between the structure of parts and components and final goods networks.

A different strand of research which aims at investigating the structure of production with network analysis is one that uses industry input - output tables. There has been an increase in the availability and quality of input - output tables to map production and value added, which potentially offer the opportunity to be analysed from a network analysis perspective. The input - output tables map supply and use between industries in a number of nations. This suggests that in network terms, the nodes need to capture both the industry and the nation; this would be represented by a set of nodes, in which each entity would represent industry *i* in country *j*, where the link between nodes would reflect the flow of goods between sectors (either domestic or foreign). A number of scholars have analysed the structure of input - output networks; one of the main reasons for this is to develop a set of statistical measures to analyse the unique and complex structure of these networks. These networks are characterised by a high density and a strong tendency for self-loops, in which goods from a sub sector of industry *i* in country *j* flow to another sub sector of industry *i*, and still in country *j*. This is a result of the data used to construct the network, as input - output data is often defined at the macro sector level, therefore the self-loops reflects the flow of goods within the broad industrial classification, within the same nation (Cerina et al, 2015; Zhu et al, 2015).

The research questions that are addressed through the analysis of these input - output networks do not primarily deal with explaining economic phenomena, such as the organisation of production. For instance, McNerney et al (2013) focus on testing statistical physics models on the network, applying community detection techniques to identify groupings in this unique network. Along similar lines, Blöchl et al (2011) present an assessment of centrality measures in a network characterised by self-loops, rather than examining economic phenomena.

To conclude, network analysis seems particularly valuable in identifying patterns and trends in the international organisation of production, assessing the rise of certain nations, changes in the overall structure, and capturing the interdependencies that characterise production today.

3.5a The regionalisation versus globalisation debate: traditional approaches

Alongside research on the fragmentation of production, another area which has attracted a high level of scholarly interest from a range of disciplines and with a number of significant policy implications, is the issue of whether production and trade today are regional or a truly global phenomena (Los et al, 2015). The economist Richard Baldwin has contributed significantly to this debate, in which he strongly argues that production is a regional phenomenon characterised by regional production blocs (Baldwin, 2006). He goes on to suggest that production is characterised by a number of regional factories, such as Factory Asia and Factory Europe, which depend on a headquarter economy, such as Japan or Germany (Baldwin, 2012). Baldwin & Lopez-Gonzalez (2015: 1695) go a step further and clearly state that "supply chain trade is not global, it's regional".

Lejour et al (2014) make use of a *hubs* and *spokes* concept in order to examine global production networks. They find (in line with the work of Baldwin, 2012) that production networks are actually characterised by regionalisation; mainly located in North America, Europe and South East Asia; however, the sub regions of these areas play different roles within production as either a hub or a spoke. Lejour et al (2014) define hubs as regions or nations which import a large portion of value added inputs to use in the output for final use in foreign markets. Whereas spokes are defined as regions or nations which are important suppliers of intermediate inputs to the hubs. For instance, in the European regional production bloc (or Factory Europe), Germany acts as the hub.

In contrast, Los et al (2014) model the input - output structure of the world economy and note that GVCs are converging towards being truly global. They suggest that the support for regionalisation by Baldwin & Lopez-Gonzalez (2015) is a result of double counting in their data, which they suggest is a result of focusing on intermediate inputs, rather than mapping value added. While they make a relevant contribution, further investigation is required, perhaps by adopting a more sectoral perspective.

3.5b The regionalisation versus globalisation debate: a network perspective

A number of scholars have approached the regionalisation versus globalisation debate making use of network analysis techniques; one frequently used approach is to apply descriptive statistics to evaluate the overall connectivity of the network, and the extent to which nations are integrated according to region in the ITN (amongst them Kim & Shin, 2002; Kastelle et al, 2006; Duernecker et al, 2012; Iapadre & Tajoli, 2014). Along similar lines to traditional approaches, there is somewhat mixed support, with Kim & Shin (2002) noting that globalisation and regionalisation are not necessarily contradictory processes.

Amighini & Gorgoni (2014) apply an alternative network technique to consider whether production in the automotive industry is more regional or global. They make use of an E-I (External – Internal) index, which assesses the number of internal and external ties in a regional partition (see Krackhardt & Stern, 1988 for an overview of this method). This method assesses the extent to which trade in each partition is regional, and presents an overall score, which indicates whether overall trade is more regional or global.

A further method applied to assess whether trade is regional or global is community detection (Gomez et al, 2013), capturing whether trade is organised into blocks characterised by a geographic partition. The method of community detection is often applied by network analysts across a number of disciplines, where a community refers to an area of the network which is denser than other regions (Robins, 2013).[11] Community detection goes further than descriptive measures or the E-I measures based on counts of ties. Community detection provides a quantitative method to identify whether trade is regional or global; going beyond the hub and spoke concept and other traditional techniques, with an empirical approach which can assess whether or not trade is organised according to regional partitions. Furthermore, community detection can also be applied to assess the impact Regional Trade Agreements have on patterns of international trade (see Reyes et al, 2014 for an empirical application).

A further contribution of network analysis to the regionalisation versus globalisation debate is provided by Standaert et al (2015). They provide a discussion of the distance puzzle by analysing the ITN through a historical perspective; making use of a unique dataset mapping trade flows from 1880 to 2011 (accounting for missing data through a

[11] A vast amount of literature has been devoted to improving these community detection techniques (see Blondel et al, 2008 for a review).

number of novel techniques). This approach allows to compare the two waves of globalisation, the first in the early twentieth century and the second in the latter half of the twentieth century.

Typical methodologies attempt to detect regionalisation of trade patterns through a variety of techniques, such as considering it within the gravity model, and examining intensity indices (Iapadre & Plummer, 2011). Whereas trade intensity measures and gravity models focus on the dyadic perspective, a network perspective can examine higher order effects, and is able to capture the impact that local trade ties have on the overall network structure of international trade (Piccardi & Tajoli, 2012). This suggests that network analysis can complement these typical measures and provide a further contribution in considering the regionalisation versus globalisation debate. Additionally, network analysis allows for a detailed examination of local structures, considering whether a nation acts like a hub in the system at the regional level. Descriptive network measures provide a way in which to evaluate the importance of a nation in the network, both at the local regional level and in the entire ITN (Iapadre & Tajoli, 2014).

3.6. Summary

This section has discussed network analysis' contribution to key topics in IBE, along with highlighting where network analysis can potentially contribute further. When examining the literature on MNE activity, the review demonstrated that a network conceptualisation of business groups as ownership networks presents significant potential in addressing research questions in IBE, such as those regarding the strategic decisions of EMNEs, along with operationalising theoretical approaches, such as the LLL framework.

The extant literature on international trade highlights network analysis presents a technique to better capture the interdependent nature of trade in the global economy. The extant network studies of the ITN emphasise that network analysis can be utilised to identify key players in international trade, especially the rise of emerging economies in the world system. The frequent use of descriptive statistics in the literature employing network analysis to the ITN indicates a further area where network analysis can contribute, more specifically through the application of advanced network models, where interdependence is often at the heart of these models (see section four for further details).

Studying patterns of FDI represents an area where network analysis can further contribute in order to better map the interdependent nature of investment decisions of firms, along with the aggregated FDI patterns of nations. The challenge would be the construction and development of relevant datasets mapping FDI, to build on the limited studies tackling international investment research questions from a network perspective.

The review of the fragmentation of production literature highlights that this is a key area where network analysis can make a significant contribution. The descriptive studies examining production patterns based on disaggregated trade data demonstrate how network analysis can be used to identify the rise of key suppliers and regional production patterns in the global economy (such as Amighini & Gorgoni, 2014; Blázquez & González-Díaz, 2015). This is an area where network analysis can further contribute through advanced network models, going beyond identifying key players, rather identifying patterns that characterise production at the sector level (see section four for further details).

The review has identified that substantial work has been undertaken to examine regional trade patterns utilising network methods. One area where network analysis can further contribute is a more detailed examination of the effect of trade at the regional level on overall global trade patterns.

The next section provides a more detailed overview of where advanced network models can provide a contribution to the central research themes in IBE.

4. More advanced network models

The field of network analysis is a relatively young and dynamic one. Advanced statistical network models have experienced rapid development and attention in recent years. Whilst descriptive analysis provides a useful contribution, allowing active and important players to be identified in the network, advanced statistical models allow for a deeper understanding of network formation and evolution. These models can constitute an improvement on standard statistical techniques in addressing research questions in IBE, as they take into account interdependencies and allow for the full network structure or actor attributes to be explained. In particular, they provide an opportunity to model the interconnected phenomena identified by the stylised facts presented in section two.

4.1. Exponential Random Graph Models (ERGMs)

There has been a surge in the work extending and improving upon Exponential Random Graph Models (ERGMs). The ERGM represents a probability distribution of all possible graphs on a fixed node set; and the probability of observing a graph is dependent on the local network configurations defined in the model (Robins et al, 2007). ERGMs can test hypothesis at the very local level, where the model is able to identify micro configurations that represent a theoretical process, and then calculates whether this process is seen in the network more than a researcher would expect by chance. A very simple micro configuration is reciprocity, (yet higher order configurations are also available), in the context of the ITN reciprocity refers to the case in which two nations both import and export from one another; the ERGM would provide a count of observed trading relationships, and would assess whether there is a higher tendency for reciprocal trade relationships in the observed network than would be expected by chance (Borgatti et al, 2013). The application of ERGMs to international trade or investment data is relatively limited, with a notable exception being Chu-Shore (2010) with a study on homogenizing effect of trade on cultural goods.

The limited application of standard ERGMs may be explained by the fact that until recently they could only deal with binary cross sectional data. However, in recent years a number of extensions have overcome these limits. Longitudinal ERGMs have been developed, specifically Separable Temporal ERGMs (STERGMs) introduced and developed by Krivitsky & Handcock (2014), which not only allow for a longitudinal analysis to explain the duration of ties, but also enable to distinguish the factors explaining the formation of ties in a network from those explaining their dissolution. Application of these models appears particularly promising in the area of FDIs and trade agreements for instance.

In the study of international trade, it has long been important to consider valued trade flows. Thus, the fact that the standard ERGMs (and some of the other extensions) can only deal with binary ties has been another important reason explaining their limited application, as it can lead to a loss of important information and introduce biases (see Thomas & Blitzstein, 2011 for a discussion of dichotomizing ties). ERGMs have however been extended to be used with valued network data (Desmarais & Cranmer, 2012a; Wilson et al, 2015). Krivitsky (2012) defines an ERGM for count data, which deals with configurations related to tie dispersion; where these parameters capture the spread of the intensity of interactions. For instance, an actor may have weaker ties (such as infrequent interactions) with a large number of actors, and a set of strong ties (a high level of interaction) with only a small number of actors.

Recent advances in ERGMs have also led to new ways to model spatial effects in a network, therefore provide a framework to better assess the "puzzle" of distance in international trade. Daraganova et al (2012) develop an ERGM which is able to capture the spatial embeddedness of network ties; they do this by specifying a distance interaction function. The model allows the researcher to consider whether spatial processes are able to explain other network structures such as the propensity for triads in the network. Koskinen & Lomi (2013) and Koskinen et al (2015) make use of this approach in considering spatial distance when modelling longitudinal FDI flows, in which they demonstrate that spatial embeddedness and endogenous network effects both drive the dynamics of FDI flows over time. However, it must be noted that the aims of these works are chiefly methodological, with the aim of developing improved longitudinal ERGMs, rather than explaining the economic phenomenon. Sohn et al (2013) investigate the influence of geographic context on the formation of policy networks through an ERGM. They approach this in a somewhat different manner than Daraganova et al (2012) and Koskinen & Lomi (2013), in that they consider both distance and the presence of territorial borders in their modelling specification, so go beyond the typical approaches in considering the spatial aspect.

These studies illustrate the scope to further consider the effect of distance when considering international trade and investment, and to investigate the interaction between spatial proximity and higher order network patterns (or trading patterns). However, it must be noted that the geographic implementation of ERGMs is not readily available in many SNA packages, and is yet to be implemented for a number of the other ERGM extensions (such as the valued and multilevel case).

In addition to the longitudinal and valued extensions, there has been a more substantial extension to ERGMs, which has a large scope in terms of its application to IB and explaining the phenomena that characterises the global economy; this is the multilevel ERGM developed by Wang et al (2013). This model applies an ERGM to a multilevel network, which is defined as a network with two node sets (A and B), and multiple linkages. The multilevel network is constituted by three networks: (1) network A, and the ties between actors in this network (the macro level); (2) network B, and the ties between the actors in the network (the micro level); (3) network X, containing the actors from networks A and B, and the ties linking the actors across these two networks (the meso level). These three networks combined form the full multilevel network. This model can be used to determine whether the structure at one level – for example ownership ties between firms in different locations – determines the structure at another level, such as the ITN. This multilevel network analysis would allow for an identification of the local patterns and empirical regularities of trading and investment patterns within the sector under investigation, such as examining the tendency for intra-firm trade.

4.2. Latent Space Models for Network Analysis

A further set of models which can be applied to relational international trade data are latent space models introduced by Hoff et al (2002). In this class of models, the probability of a relation between actors depends on the positions of individuals in an unobserved "social space." Latent space models assume that each node in the network has some unknown position in the Euclidean latent space. Where the probability of a link forming between two nodes depends on the distance between their positions in the latent space, and between their observed characteristics. The closer two nodes are in the latent space, the more likely it is for a link to be established between them. The authors make inference for the social space within maximum likelihood and Bayesian frameworks, and propose Markov chain Monte Carlo procedures for making inference on latent positions and the effects of observed covariates.

The model was then extended by Handcock et al (2007), to model the clustering of latent space positions of actors, identifying groupings of nodes. Krivitsky et al (2009) then built on this to construct a latent cluster random effects model, which is able to explicitly model homophily, clustering and degree heterogeneity of actors. The latent space model captures higher order network effects naturally (rather than directly modelling them). For instance, in the case of transitivity, this is captured by the model, as two actors with a third actor in common are assumed to be relatively close to each other in the latent space, therefore making connected triangles in the network more likely (Rastelli et al, 2015).

One set of latent space models which have received attention are the General Bilinear Mixed Effects (GBME) models (Hoff, 2005). In demonstrating the value and applicability of these models, authors often make use of international trade data, for instance, the longitudinal extension developed by Westveld & Hoff (2011). Ward et al (2013) develop a GBME model to account for both valued and longitudinal data, applying it to international trade data to theoretically extend the gravity model with relational effects. They identify the presence of higher order effects, and that the inclusion of these relational effects out performs standard specifications that ignore the interdependencies in international trade data.

Latent space models are primarily designed to analyse clustering patterns, and the positions and behaviour of groups of actors. Whilst latent space models and ERGMs both represent advanced statistical models to analyse network data, they take very different approaches, and address different research questions. The research questions which these latent space models are able to answer include whether there are cohesive groups of actors in the network? How are individual actors positioned in these groupings? ERGMs on the other hand, test the propensity for local substructures, and whilst there is some overlap in the two, (for instance, they are both capable of examining patterns of structural equivalence in the network), they are primarily distinctive approaches.

When comparing ERGMs with latent space models, there is not one modelling approach that is better than another, rather that these models are equipped to answer different research questions, especially when considering the more recent extensions to ERGMs (such as the multilevel case). Latent space models still hold a number of advantages in considering longitudinal and valued data, along with their ability to identify clustering patterns. In terms of international trade, the research areas in which latent space models hold potential include mapping how the position of emerging economies (in particular the BRIC nations[12]) have changed over time. Do these nations hold similar positions? Do patterns of regional clustering emerge? If so, what are the positions of individual nations in these clusters? Have emerging economies moved into positions previously held by industrialised nations?

The best approach depends on the problem and research questions, with the main distinction that latent space models are better in answering questions regarding clustering, and ERGMs oriented to consider topics in which dependence is at the heart of the research problem.

4.3. Auto Logistic Actor Attribute Models (ALAAMs) & Network Autocorrelation Models (NAMs)

Another family of network models exist to attempt to explain actors' attributes based on the network structure. Although these are primarily used in contagion studies and the spread of opinions and behaviours, they can also be utilised in economics or business to

[12] Brazil, Russia, India and China

investigate how network structure affects actor attributes such as performance or competitiveness. Amongst these models is the Auto Logistic Actor Attribute Model (ALAAM), which is similar to the ERGM family of models, yet instead of modelling the network structure as a function of exogenous actor covariates and endogenous network processes, a characteristic, such as behaviour or performance is modelled. This modelling approach allows for an investigation into the extent to which an actor's attribute is constrained by its position in the network and the attribute of its connections. Unlike ERGMs, the network ties are considered exogenous, and are not changed by attributes. The ALAAM models an actor's (binary or auto logistic) attribute as a function of exogenous tie variables and other exogenous attributes, and has the capabilities to predict the attributes of actors (Daraganova & Robins, 2013). For instance, Daraganova & Pattison (2013) address unemployment patterns through an ALAAM, in which they consider the association between the employment status of an individual, social ties and spatial proximity, where the employment status is the attribute being modelled, with the social ties and proximity as the exogenous variables (as ALAAMs have only been developed relatively recently, this unemployment example represents one of the few empirical implementations of the model).

An example of a research question in relation to international trade would be to what extent are the trade patterns (in a certain industry) associated with the competitiveness of nations. As Kinra & Antai (2010: 104) note, the rise of inter-organisational networks in complex supply chains has altered the way competitiveness it viewed, with an increase in popularity of approaches that seek to "advance competition based on structural characteristics seen either from the point of view of the individual firm or at the national level." This suggests that a relational approach to assess the competitiveness of nations can provide a contribution, potentially through the use of an ALAAM. In the context of international trade and competitiveness, the attribute being modelled would be the competitiveness of a nation, and the exogenous tie variables would refer to the trade ties, with other exogenous attributes referring to country level covariates, such as GDP and regional partition. Therefore, the model would chiefly consider the extent to which a nation's competitiveness is a result of its participation in certain trading patterns and relationships.

Alternatives to the ALAAMs to model actor attributes are Network Autocorrelation Models (NAMs); this set of models has been widely applied in SNA, where they are often considered the standard bearers for empirically modelling social influence and contagion patterns in network settings (Fujimoto et al, 2011). NAMs were first developed and applied in spatial statistics as a solution to dependence issues observed in the error terms of regression analysis when modelling spatial data (see Cliff & Ord, 1972). The NAM has the potential to be applied to a number of network settings, where it allows to capture the extent to which the behaviour of an alter impacts the behaviour of an ego within a network (see Leenders, 2002 for a detailed overview of the model). Therefore, in the context of the ITN, the NAM could be applied to assess how developing efficient trade ties with competitive countries impacts performance.

The use of the application of ALAAMs or NAMs to the context of international trade would allow, for example, to operationally explore the extent to which competitiveness is a relational phenomenon.

To conclude, recent developments in network modelling provide further opportunities for examining and explaining the economic phenomena which characterise the world as it is today, especially patterns of international trade. In particular, the use of STERGMs allows to better explain what trade patterns have been preserved over time, and what factors explain the development and the dissolution of trade ties, while the multilevel ERGM would allow to overcome the fictitious separation between the micro and the macro level to investigate micro determinants of ties observed at the macro level. In addition to this, actor attribute models such as ALAAMs or NAMs, provide a basis to examine actors' attributes and explain the extent to which this derives from their network.

5. Concluding Comments

The first part of this paper has discussed how the changes in MNE activity, FDI and international trade, which characterise the global economy today (the stylised facts) have been investigated in the IBE literature. Additionally, through the use of a citation analysis and thematic survey it has gone onto identify a number of themes driving the IB and IE research agenda, under which the stylised facts identified are investigated, in order to address the research questions regarding whether the stylised facts are sufficiently captured and addressed in the IBE literature (research questions one and two).

The second part of the paper then analysed the typical frameworks applied in approaching these themes (in order to answer research question three), along with a review of the extant literature in which network analysis has been applied (addressing research question four). An overview of advanced network models was presented in the last part, demonstrating potential contribution of these models to the important thematic areas in IBE. In particular, what has emerged from this review is that there has been a paradigm shift: production, trade and investment patterns have changed, with products no longer being produced in a single location; rather fragmented into separate production sites across the globe. This has resulted in many scholars urging for a relational, network perspective, at least at the conceptual level, in order to capture the interconnected and interdependent nature of production, trade and investment which characterises the world economy as it is today.

This paper has examined how network analysis provides an empirical toolkit to investigate the international fragmentation of production, trade and FDI, along with the increasingly important role of MNEs. The paper has demonstrated the value of network analysis through a review of the current contributions of network analysis to the field, and how these complement the more typical approaches. Additionally, advanced network models present new avenues for future research. In particular, the value of a multilevel network analysis has been discussed, which would allow researchers to overcome the fictitious separation of the micro (firm) level and macro (country) level when investigating issues related to the international organisation of production. Furthermore, this model provides a tool which can be applied to identify the trading and investment patterns which characterise sectoral production, such as whether trade in the sector is characterised by trade in final goods, or intra-firm trade.

Appendix

A – International Economics Thematic Survey

Thomson Reuters Web of Science allows a user to search by publication, outputting a list of articles published from that specific journal for a certain time period. Web of Science additionally provides the number of times each article has been cited (along with the specific source of the citation). In this paper, two searches were undertaken, both for the period January 2004 to February 2015. The first considered a set of relevant international economics journals; furthermore, this search was combined with a topic search of the term "international trade and investment". This was undertaken to produce a list of articles from the most relevant publications which consider international patterns of trade and investment; subsequently a thematic survey of this work was completed, (grouping articles according to topic). This allowed for an investigation into the extent to which the phenomena characterising the global economy is addressed in international economics literature.

The publications examined in this thematic survey include the *Journal of International Economics*, *Review of International Economics*, *Review of World Economics*, *International Economic Review*, *World Economy* and the *Review of International Political Economy*. A description of the selection criteria will be outlined below. The Web of Science search produced an output of 165 articles, which are cited 2,174 times.

Out of these 165 articles, the majority were published in the *Journal of International Economics* (68) and the *World Economy* (39), accounting for 65% of the total output of this search. Furthermore, the work published in these journals also reflect the most cited works, with the articles in these two journals accounting for 88% of total citations from this search output. This suggests that out of these relevant publications, these two hold the most influential positions. In particular, the *World Economy* may be considered one of the most relevant journals in addressing the changes in the world today; additionally, a number of works published here have utilised network analysis in considering research questions pertaining to areas such as international trade and production. For instance, one of the most cited works from this journal (yet not included in the output of this search, as it does not deal with international investment) is De Benedictis & Tajoli (2011), which can be considered a key reference for any work applying network analysis to international trade.

The analysis of IB and IE literature was conducted using different techniques for a number of reasons. The purpose of the analysis of the literature was to consider the extent to which the field of IBE captures the changes to the global economy, and that these changes fundamentally pertain to patterns of trade and FDI (see the stylised facts outlined in section two).

Therefore, in selecting the relevant journals, the purview of these publications must cover the areas related to the stylised facts outlined in section two (at least to some extent). Within the field of IB, the leading journals present a set of relevant publications, which specifically deal with MNE activity. They publish work which relates to the international activity and investments of firms and multinational groups (amongst other topics). Therefore, considering these works within the Web of Science search criteria produces a substantial amount of output, where a citation analysis provides a useful tool to identify the topics considered significant to the field.

Leading economics journals consider a broader range of topics in their purview, and often do not primarily focus on international trade and FDI themes. Therefore, to better assess whether the literature captures the changes to the global economy, a set of IE journals were selected for analysis. However, these still focused on a number of areas not directly related to patterns of international trade and FDI (such as international finance). In order to undertake a more focused assessment of the works related to the stylised facts outlined in section two, a further search criteria was applied; searching for works published in these publications on the topic of international trade and investment.

A citation analysis of this output, however, was inappropriate, as although the journals selected were more relevant, their citation impact was much lower (especially when compared to the leading IB journals), and was diverse amongst the six publications selected. For instance, a citation analysis of the output, would simply indicate the work from the *Journal of International Economics*, as the most influential, with many of the other publications having a substantially lower number of citations.

The output of the search was significantly smaller than that of the leading IB journals and as a citation analysis was considered unsuitable, a thematic survey was undertaken. The thematic survey provided a more appropriate technique in identifying the main topics analysed and empirical strategies applied in the discipline, as demonstrated by the results presented in Table 1.

Table 1 Major themes addressed in IE journals dealing with international trade & investment topics

	Articles	Subtheme Articles
Firm Dynamics	18	
Firm internationalisation status & productivity		13
Characteristics of international firms		3
Firm innovation status & productivity		2
MNE Behaviour & International Strategies	16	
Exports vs FDI		3
MNE performance vs national firms		1
MNEs & bargaining power		3
Locational decisions of MNEs		2
MNEs & knowledge spill overs		2
MNEs & cross border investment choice		1
Other		4
International Trade	35	
International trade & international agreements & policy		8
International trade & knowledge spill overs/transfers		2
International trade & the role of distance		1
International trade & migration		2
International trade & integration into the global economy		3
Relationship between FDI & international trade		1
Trade liberalisation		4
International intellectual property		2
Other		12
FDI	37	
FDI & international agreements		5
FDI & knowledge spill overs/transfers		9
FDI & the role of distance		3
FDI & intellectual property		2
FDI & integration into the global economy		2
FDI & model development		2
Other		14
Fragmentation of Production	17	
International sourcing strategies		5
Global Value Chains (GVCs)		2
Vertical specialisation		1
Intra industry trade		1
Other		8
International Finance	18	
Cross border capital flows		5
Tax		3
Other		10
Globalisation	4	
Other	20	
International trade & investment & exchange rate movements		6
International business cycles		5
The transmission & diffusion of shocks & fluctuations		3
International trade & investment & environmental regulations		6

B – International Business Citation Analysis

The second search utilising Thomson Reuters Web of Science was conducted with the aim of identifying the work driving international business, searching for all work published in the leading international business journals over the last decade (January 2004 – February 2015). This search produced a list of articles, which were then sorted according to number of citations. The top fifteen most cited works were examined, where these were considered the most influential articles. These articles were then assessed to consider the extent to which the influential work in IB considers the phenomena outlined in section two. Citation analysis provides a useful tool in which the interests and views of the research community of a given field can be assessed and provides insights into the fundamental themes driving forward the research agenda (Chandy & Williams, 1994).

The journal selection for analysis (and use in the Web of Science search criteria) was based on the work of DuBois & Reeb (2000). They ranked the journals in IB through the use of a thorough citation analysis and survey approach. Therefore, the leading journals selected for the citation analysis in this paper applied their ranking, extracting the top six journals (*Journal of International Business Studies, Management International Review, Journal of World Business, International Marketing Review, Journal of International Marketing and International Business Review*). The ranking of journals by DuBois & Reeb (2000) has been utilised in a number of other literature reviews of international business. For instance, Griffith et al (2008) make use of the ranking system to examine the emerging themes and prominent research questions from the top six IB journals from 1996 – 2006.

The citation analysis presented in Table 2 is primarily dominated by the *Journal of International Business*, however, an examination of the other five leading IB journals points towards a similar set of emerging themes. For instance, considering the most cited works from *International Business Review* and *International Marketing Review*, one theme which clearly emerges is work examining the behaviour and internationalisation strategies of “born global” firms (Gabrielsson et al, 2008; Freeman et al, 2010; Styles et al, 2006; Knight et al, 2004).

Table 2 The 15 most frequently cited articles in IB: January 2004 - February 2015

Article	No. of Citations
Knight, G. A. and Cavusgil, S. T. (2004) Innovation, organizational capabilities, and the born-global firm, Journal of International Business Studies, 35(2), pp. 124–141.	366
Kirkman, B. L., Lowe, K. B. and Gibson, C. B. (2006) A quarter century of Culture's Consequences: a review of empirical research incorporating Hofstede's cultural values framework, Journal of International Business Studies, 37(3), pp. 285–320.	345
Peng, M. W., Wang, D. Y. L. and Jiang, Y. (2008) An institution-based view of international business strategy: a focus on emerging economies, Journal of International Business Studies, 39(5), pp. 920–936.	337
Rugman, A. M. and Verbeke, A. (2004) A perspective on regional and global strategies of multinational enterprises, Journal of International Business Studies, 35(1), pp. 3–18.	336
Luo, Y. and Tung, R. L. (2007) International expansion of emerging market enterprises: A springboard perspective, Journal of International Business Studies, 38(4), pp. 481–498.	304
Johanson, J. and Vahlne, J.-E. (2009) The Uppsala internationalization process model revisited: From liability of foreignness to liability of outsidership, Journal of International Business Studies, 40(9), pp. 1411–1431.	297
Buckley, P. J. and Ghauri, P. N. (2004) Globalisation, economic geography and the strategy of multinational enterprises, Journal of International Business Studies, 35(2), pp. 81–98.	256
Leung, K., Bhagat, R. S., Buchan, N. R., Erez, M. and Gibson, C. B. (2005) Culture and international business: recent advances and their implications for future research, Journal of International Business Studies, 36(4), pp. 357–378.	234
Dhanaraj, C., Lyles, M. A., Steensma, H. K. and Tihanyi, L. (2004) Managing tacit and explicit knowledge transfer in IJVs: the role of relational embeddedness and the impact on performance, Journal of International Business Studies, 35(5), pp. 428–442.	207
Rialp, A., Rialp, J. and Knight, G. A. (2005) The phenomenon of early internationalizing firms: what do we know after a decade (1993-2003) of scientific inquiry?, International Business Review, 14(2), pp. 147–166.	206
Tihanyi, L., Griffith, D. A. and Russell, C. J. (2005) The effect of cultural distance on entry mode choice, international diversification, and MNE performance: a meta-analysis, Journal of International Business Studies, 36(3), pp. 270–283.	204
Mudambi, R. and Navarra, P. (2004) Is knowledge power? Knowledge flows, subsidiary power and rent-seeking within MNCs, Journal of International Business Studies, 35(5), pp. 385–406.	204
Jones, M. V. and Coviello, N. E. (2005) Internationalisation: conceptualising an entrepreneurial process of behaviour in time, Journal of International Business Studies, 36(3), pp. 284–303.	201
Chang, S.-J., van Witteloostuijn, A. and Eden, L. (2010) From the Editors: Common method variance in international business research, Journal of International Business Studies, 41(2), pp. 178–184.	186
Meyer, K. E. and Peng, M. W. (2005) Probing theoretically into Central and Eastern Europe: transactions, resources, and institutions, Journal of International Business Studies, 36(6), pp. 600–621.	185

C – A brief comparison of IE & IB literature

IE and IB journals citation patterns have been considered individually, as their approach and focal interests are often diverging, especially when considering research questions concerning production. With IB focusing often on more qualitative firm level studies, with the MNE as the level of analysis. Whereas in IE, quantitative approaches are pursued (such as general equilibrium models), with an emphasis on the nation state as the level of analysis (Ietto-Gillies, 2007).

The themes that emerge from the citation analysis and thematic survey are not only driven by the phenomena characterising the global economy; they are also driven by the extant theories and methodologies. For instance, within IE, Melitz (2003) and Helpman et al (2004) developed models which determine the relationship between firm productivity, export market entry and firm survival. This has resulted in a large portion of work driven by the development of these models, reflected by the 649 citations of Helpman et al (2004) in published works.

D – International Organisations

Thomson Reuters Web of Science collection covers a wide range of journals and topics, however, it omits a number of important works pertaining to the structure of trade, investment and production flows; the works of international organisations. International organisations such as the OECD and UNCTAD have recognised the changes of production and trade patterns. For example, UNCTAD (2013) provides a detailed overview of the changes and implications of the fragmentation of production, along with the efforts of these international organisations to improve the quality of datasets used to analyse this phenomenon. A particular framework has emerged as the prominent tool applied by these organisations to consider the changes to the world economy: Global Value Chains (GVCs). UNCTAD (2013: 2) note a range of research questions with important policy implications that can be approached through the use of a GVC framework, such as how much value added does trade actually generate, who reaps the value and how do international production networks of MNEs shape value added trade? Gereffi (2014) suggests that the popularity of the GVC framework amongst international organisations is a result of the exploratory power of the GVC paradigm, that it is able to link research on globalisation with policy issues, such as economic growth and development.

II – A Multilevel Network Analysis of the International Fragmentation of Production in a High-Tech Industry

1. Introduction

In recent decades, there has been a structural change in the way production is organised; with products no longer being manufactured in their entirety in a single location. Rather, production is fragmented into a number of stages, geographically spread internationally, with a rise in the level of trade in intermediate goods and intra-firm trade (Helg & Tajoli, 2005; UNCTAD, 2013). Fragmentation is due to outsourcing (Jones & Kierzkowski, 2005), as well as to the development of what Hanson et al (2005) call “vertical production networks”, which describes the trade between the parent and affiliate companies located abroad. The fragmentation of production is referred to using numerous terms to describe the same phenomenon, amongst them slicing the value chain (Krugman et al, 1995), vertical specialisation (Hummels et al, 2001) and production sharing (Yeats, 2001); this variation in names indicates interest in this important topic, yet suggests some ambiguity in its definition and the various perspectives from which it is approached.

Baldwin (2006) argues that the fragmentation of production is due to what he refers to as the “second unbundling of globalisation”; where the first unbundling occurred in the late nineteenth century when steam power reduced transport costs. He notes that the second unbundling has occurred in more recent decades as a result of changes in communication technology and reduced transport costs, allowing for the production process to be “unbundled” into separate stages across the globe (Baldwin, 2014). Traditional approaches used to investigate international trade and FDI, such as gravity models, often fail to recognise the interdependencies which characterise trade and investment patterns as they are today. These models assume that firm decisions to export, import and invest in a nation are made in isolation of other trading and investment relationships. This is a strong assumption, and in a world characterised by interdependent production strategies, a different methodological tool is called for, which recognises the dependencies between trading and investment decisions. The first paper of this thesis highlighted that the limitations of standard quantitative techniques has led to the implementation of alternative methodological frameworks to investigate the fragmentation of production, many of which conceptually propose a relational approach.

This study aims at contributing to the field of research investigating the international fragmentation of production. This paper provides an analysis of international trade and investment and therefore production patterns in the medical and precision instruments sector - a high tech sector - where the UK already holds notable strengths (BIS, 2010). Furthermore, this sector is not only important to nations in terms of the value it contributes to the manufacturing sector, it also has a strong link to the service sector, where post sale services play a key role in the medical and precision instruments industry (Sturgeon et al, 2013).

In order to provide some insights into the fragmentation of production as it is today and the characteristics of the medical and precision instruments manufacturing industry, this study makes use of both firm and country level data, the former being ownership data from Orbis and the latter international trade data from UN Comtrade. These two data sources are then used in the construction of a multilevel network, analysed using a multilevel Exponential Random Graph Model (ERGM), a sophisticated and advanced methodology for the analysis of multilevel networks. This paper provides a unique contribution in the creation of this dataset, as it brings together several secondary sources in order to create a multilevel dataset that provides the opportunity to uncover a number of characteristics to inform on the organisation of production of medical and precision instruments.

This approach is used to answer a number of research questions, including to what extent do ownership relations and the locational choices of firms contribute in explaining overall trade patterns in the medical and precision instruments sector? Furthermore, the use of this advanced network model allows the investigation of what patterns of trade and investment characterise the sector, such as whether trade is a result of intense investment amongst nations and whether there is a propensity for intra-firm trade.

This study has the potential to inform on a number of policy-related areas, as it provides a detailed description of the production process at the business function level. A number of researchers have reported the policy implications when examining the fragmentation of production and tracing valued added through global supply chains. For instance, Baldwin & Evenett (2012) provide guidance on how policy should be framed in light of the disintegration of production; policy should be conceived at the task or stage level rather than at highly aggregated macro sector levels.

The paper is structured as follows, with section two outlining current attempts to map the fragmentation of production, along with the extant literature applying network analysis considering the reorganisation of production. Furthermore, this section outlines the rationale for a multilevel network perspective, along with the contributions of a multilevel analysis. Section three provides an overview of the sector under examination – the manufacture of medical and precision instruments. Section four presents a description of the multilevel dataset, along with a full descriptive analysis of the multilevel network (by parts) and maps each of the individual networks. It then presents the ERGM and its multilevel extension. This is followed by a section presenting the modelling results of the advanced network model. Section six then provides a discussion of the findings and policy implications. This is followed by a section providing some concluding comments, discussing the limits of the work and possible avenues for future research.

2. Literature Review

This section presents an overview of the typical approaches to analyse the fragmentation of production, along with an overview of extant literature utilising network analysis to examine these patterns. It then outlines the need for a multilevel approach and improved datasets to consider production patterns. This section concludes by presenting the research questions addressed by this paper.

2.1. A network view of fragmentation

The reorganisation of production provides a number of challenges to standard methodological approaches, in particular the independence assumption. These challenges to standard techniques have led to the implementation of various other methodological frameworks to investigate the fragmentation of production. One of the most frequently applied frameworks is that of Global Value Chains (GVCs); where they map the production of a good from its conception to end use and beyond over a wide geographic space (Gereffi et al, 2005), primarily addressing research questions such as where is value added along the chain, and who reaps the value? However, whilst a very useful conceptual tool in examining production patterns, the typical methodological approach is to make use of qualitative case studies, which have had limited generalisability.

In recent years the GVC framework has been applied in more quantitative empirical setting, rather than the traditional case study approach; this is a result of improvements of available data, specifically input - output (I-O) tables. For instance, Johnson & Noguera

(2012) make use of global I-O tables to map value added and the growth of production sharing over time. Although these tables provide a novel and important way to map the fragmentation of production and the flow of value added, this data also has its limitations. Firstly, in terms of coverage, this database is not as extensive as standard international trade data (as provided by UN Comtrade), as the majority of these databases only cover around forty to fifty nations, focusing on OECD members, for years 1995 - 2011 (see UNCTAD, 2013 for a description of these I-O databases and their coverage). Secondly, I-O datasets often require a high level of statistical manipulation and processing before use in empirical studies (McCleery & DePaolis, 2014). Furthermore, the level of aggregation of the industry classifications is rather broad, defining macro sectors; therefore there is a loss of information, especially when considering the fragmentation of production (Escaith, 2014).

The interdependent nature of industries and I-O data makes network analysis seem a natural choice to map these patterns; where I-O tables map the flow of supply and use between industries, both within and between nations. But when I-O tables are mapped as a network, it is characterised by a high density, almost completely connected, along with a high level of self-loops. Therefore, the majority of studies examining the network structure of these I-O tables attempt to develop methods analyse to these unique and complex networks, rather than attempting to answer research questions relevant to international business and economics (Blöchl et al, 2011; Cerina et al, 2015; Zhu et al, 2015). However, there is a need to assess whether typical descriptive statistics or network models, even those modified to fit very dense networks, can make inferences regarding international production or value chains.

A strand of literature that considers the disintegration of production in a more quantitative manner, examining the phenomena separately from the GVC framework is that which analyses multinational production, a term used to refer to foreign affiliate sales.[13] This stream of literature clearly argues the need to consider the firm as the unit of analysis to uncover patterns of trade, and the interaction with multinational production; a large amount of firm heterogeneity lies behind aggregated international trade data at the country level (Ramondo et al, 2012). However, as detailed datasets on firm trade are

[13] Antràs & Yeaple (2013) provide a review of the state of the literature on international trade and multinational firms, primarily considering the contributions and empirical implementation of more quantitative models.

widely unavailable, and those distinguishing between intra-firm and arm's length trade do not exist, these studies require detailed national data sources. Yet this type of data is only available for a small number of nations, such as information on the activities of Norwegian (Irarrazabal et al, 2013), Indonesian (Rodrigue, 2014) and French firms (Corcos et al, 2012).[14] As noted by Rodrigue (2014), this is a relatively recent (yet growing) strand of literature, with a range of themes and research questions addressed. For instance, a number of scholars have attempted to assess the gains from multinational production, and in particular the gains from intra-firm trade (Bombarda & Marcassa, 2014; Garetto, 2013).

The contribution of the multinational production literature, (which is closely connected to that of the reorganisation of production), is explaining patterns and trends of intra-firm trade; in particular that it adheres to the gravity model, specifically that it is dampened by distance (Yeaple, 2009; Keller & Yeaple, 2013; Irarrazabal et al, 2013). Furthermore, intra-firm trade is skewed, where only a handful of very productive firms participate in intra-firm trade (Haller, 2010; Ramondo et al, 2015; Alviarez, 2014).

This study makes use of network analysis in the investigation of the structure of international trade and production. Network analysis applications to international trade data date back to the nineteen seventies, with the Snyder & Kick (1979) examination of the world system through the use of blockmodelling (see Wasserman & Faust, 1994 for a definition of the term).[15]

There are only a limited number of cases where network analysis has been applied to the international trade network (ITN) to specifically investigate the area of the fragmentation of production (Srholec, 2006; Amighini & Gorgoni, 2014; Blázquez & González-Díaz, 2015). A key contribution is the case of Amighini & Gorgoni (2014), where they examine disintegrated production patterns in the automotive sector, however their work is purely descriptive. Advanced network techniques such as the one used in this study go beyond merely descriptive analysis allowing to test for processes explaining the structure of the ITN.

[14]Efforts have been made to improve country level datasets to examine multinational production, aggregating various sources (efforts include Ramondo et al, 2015 and Federico, 2016). However, as mentioned in the body of the text, a high level of firm heterogeneity and detail lies behind aggregated country datasets.
[15]See the first paper of the thesis for a review of the literature applying network analysis to examine the international trade network.

2.2. Multilevel network analysis & the fragmentation of production

In addition to the limitations of extant studies highlighted in the previous section, a crucial issue is the fact that the majority of studies investigating the international fragmentation of production lack recognition – in terms of empirical analysis – of the multilevel nature of the phenomenon.

Studies generally examine trade in isolation of FDI decisions, yet this is clearly not a realistic assumption in a world where production is a globally fragmented process, with many multinational and corporate groups utilising FDI and locational assets in their manufacturing activities to retain competitive advantages (Gray, 1996). Gammeltoft et al (2010) recognise that studies that make use of FDI stock and flow statistics only illustrate overall country patterns. This approach disregards that FDI flows are an aggregation of firms involved in international activities, and that therefore trade and investment flows are dependent on corporate networks (Park & Park, 2015). Altomonte & Rungi (2013) define these corporate networks of firms linked by ownership as business groups. These business groups play a key role in the fragmentation of production; UNCTAD (2013) noted that in 2010 these groups accounted for 80% of total trade.

Sgrignoli (2014) makes an attempt to investigate the interplay between international trade and FDI through a network perspective; examining how the FDI network influences the trade network through a set of gravity models, more specifically whether FDI complements or substitutes trade. However, within this study, inferences are made at the broad macro sector level (simply examining two sectors – manufacturing and services), neglecting that trade and investment patterns differ vastly across industries. The FDI network is a country level network constructed by aggregating a large firm level dataset, which potentially disregards additional key information, such as corporate group affiliation. Furthermore, given the increasing complexity of the production process, there is a need to consider the interplay of FDI and trade beyond the complements or substitutes classifications.

With the recent changes in the organisation of production and trade patterns, and the increase in trade of intermediate goods, the need for a methodological approach that makes use of firm level and country level data has been acknowledged by several scholars (amongst them Miroudot et al, 2009). Current datasets, however, lack the required information, especially in relation to the rise of intra-firm trade, suggesting a need to combine bilateral trade data with firm level information. Feenstra et al (2010) recognise this in their examination of the state of available data for the study of international trade and FDI. They suggest that in order to better understand the complex nature of production as it is today, there is a need for this complexity to be reflected in datasets applied, capturing the increasing importance of MNEs and intra-firm trade. The rise of GVCs has changed many of the assumptions behind statistical regimes and has led for a need for new datasets that can be used in quantitative studies; a factor additionally recognised by international economic organisations. For instance, a WTO-OECD collaborative initiative has resulted in a new dataset, Trade in Value Added, which maps valued added patterns utilising aggregate industry level I-O tables (OECD, 2013).

A range of studies have made use of alternative datasets to better explain the phenomena of multinational production. These attempts have emerged from a distinct lack of data on the activity of foreign affiliates, which is key, given the significant economic contribution of multinational firms in the global economy (Fukui & Lakatos, 2012). Amongst the attempts to create datasets on multinational production is that of Ramondo et al (2013) where they present a country level dataset, which complements the FDI stock data with additional Merger & Acquisition (M&A) data, in order to overcome missing values. This covers 61 countries for 1996 - 2001. Alviarez (2013) presents a dataset of bilateral foreign affiliate sales. This macro level dataset contains 39 nations for 10 (macro) sectors, drawing chiefly on OECD data sources, Foreign Affiliates Statistics from Eurostat, along with a number of other indicators.

However, these datasets are still at the macro country level, therefore their ability to explain the activity and complex strategies of multinationals is limited; restricted to considering only the bilateral relations between countries. Additionally, the question arises whether a solely macro level data analysis is appropriate to specifically model multinational production (or foreign affiliate activity), a phenomenon that is directly associated with research questions pertaining to the activity of firms and multinational groups.

This study makes use of a variety of secondary data sources at different levels in a multilevel network analysis, to shed light on the location of value and the positions of firms in GVCs (Sturgeon & Gereffi, 2008; Nielsen et al, 2011). The multilevel network comprises a micro level of firms, which are linked through ownership, and a macro level of countries linked by trade flows. These two levels are then linked by a firm-country affiliation level (or a meso level as defined by House et al 1995), which is made up of ties linking firms to countries, such as where they are based, where various branches are located and where capital flows to. This firm-country level can be represented by a bipartite network of countries and firms.

The full multilevel network is then analysed using the recently developed model introduced by Wang et al (2013). The inclusion of the firm level data is very important, as firms drive the fragmentation of production and therefore shape the trade network. The use of the Wang et al's (2013) multilevel model allows the investigation of how the structure of the micro level (firm ownership) affects the structure of the macro network (country level international trade network). The industry providing the context for this study is the production of medical and precision instruments, selected as it is an example of a high tech sector (as defined by Lall et al, 2006).

2.3. Research Questions

The aim of this paper is to analyse a novel multilevel dataset in order to identify the trade and investment patterns (and therefore production patterns) that characterise the medical and precision instruments sector, specifically accounting for the increased role of multinational groups in the production process (UNCTAD, 2013).

More specifically, this paper addresses the following set of research questions:

1. To what extent is the structure of international trade and investment in the medical and precision instruments industry shaped by the ownership relations that link firms together into business groups? What effect does high levels of firm investment have on international trading patterns?
2. To what extent is the medical and precision instruments sector characterised by intra-firm trade?
3. What type of FDI characterises investment flows in the sector – resource, market, efficiency or strategic asset seeking FDI?
4. What is the organisational form of business groups in this sector – is there a tendency for foreign or domestic subsidiaries?
5. What role do lead firms play in this sector? Are nations with investment from lead firms exporters in the global economy?

This paper asks the above research questions in order to make inferences regarding the characteristics of the medical and precision instruments sector. The rise of GVCs has resulted in international trade, investment and MNE activity becoming increasingly intertwined, with an increased need to capture the extent of this interaction in a sector, in order to make clear inferences regarding fragmented production patterns in the world economy (Ietto-Gillies, 2000). Therefore, the first question this paper asks to what extent is the structure of international trade and investment in the medical and precision instruments industry shaped by the ownership relations that link firms together into business groups? More specifically, do investment patterns determine trade ties in the global economy? Does a high level of investments into a country impact its trading profile – is it more likely to export or import?

Intra-firm trade is becoming an increasingly important characteristic of the global economy (Bardhan & Jaffee, 2004), however, the levels of intra-firm trade can vary dramatically amongst industries (Hanson et al, 2005). Furthermore, there is a lack of data on intra-firm trade, therefore patterns are often only considered for a handful of individual nations (Lanz & Miroudot, 2011). This paper contributes to a gap in the literature; a distinctive lack of information regarding intra-firm trade patterns in specific industrial sectors. The novel multilevel dataset presented in this paper allows to map vertical production networks and capture intra-firm trade flows. Therefore, the following question arises, to what extent is the medical and precision instruments sector characterised by intra-firm trade?

Given the importance of MNEs in the global economy it is necessary to ask a number of questions regarding the locational decisions of firms in this sector, specifically the third research question. This paper provides a contribution in investigating the patterns of investment in this sector; more specifically; do firms invest in nations to serve end markets? What type of FDI (market seeking, resource seeking or asset seeking) characterises the medical and precision instruments sector?

As noted by Helpman (2006), it has become increasingly important to model the different organisational forms of firms and business groups involved in international activities. Therefore, the fourth research question presented allows to uncover patterns regarding the organisation of multinational groups in this sector. More specifically, this paper provides an examination of the composition of firms in this sector; whether there is the propensity for domestic or foreign subsidiaries.

The fragmentation of production is often examined using the GVC framework; the GVC approach allows to examine the key actors involved in the international production network. The notion of governance is central to the GVC framework, as it characterises within the GVC how various parameters outlining how the chain operates are enforced, and whether they are imposed by a set of lead firms (Humphrey & Schmitz, 2001; Gereffi, 2014). Lead firms refer to global enterprises that coordinate the international activities undertaken by actors in the value chain; facilitating market assess and export activity. A clear outline of the governance structure and role of lead firms in the sector allows for a better understanding of the distribution of value, along with how to shape policy to improve a country's position in the value chain (Humphrey & Schmitz, 2001). In different sectors, the lead firms may vary, along with the role they play in the production process. For instance, the apparel sector is often characterised as a "buyer driven" value chain, where the lead firms comprise the retailer. By contrast, in a high tech sector, such as the medical and precision instruments industry, the value chain is often characterised as "producer driven". Producer driven GVCs are those where the lead firms are usually large multinationals, which exert a high level of control over production activities (Gereffi, 1999).

Gereffi et al (2005) extend the buyer-producer driven governance dichotomy to include a wider range of governance forms, outlining the roles of lead firms and suppliers in GVCs; these include market, modular, relational, captive and hierarchy forms. The governance structure of the medical and precision instruments sector is producer driven with a handful of lead firms (or MNEs) dominating the market. This governance structure can then be further classified according to the Gereffi et al (2005) typology, where the sector appears to be characterised by a hierarchical structure. This indicates that the GVC is characterised by high level of vertical integration, where lead firms exert a substantial level of managerial control across the chain and within their multinational group.

The lead firms holding significant positions in this sector include a set of large American corporations, such as Medtronic Inc, General Electric Healthcare, Abbott Laboratories, Baxter International Inc, Boston Scientific and Johnson & Johnson Medical Inc (see Bamber & Gereffi, 2013 for further details regarding large US lead firms). Other key firms outside the US include Samsung's Medison (Republic of Korea), Sorin (Italy) and

Fujirebio (Japan). Therefore, given the importance of lead firms in the GVC framework and their dominant role in the medical and precision instruments sector, the question is what role do these firms play in the multilevel network; do the investments decision of these firms have a significant impact on international trade patterns?

3. The Context – The Industry for Medical & Precision Instruments

The sector under analysis is broadly categorised as the medical and precision instruments industry, which includes items such as ultrasound machines and MRI systems. In the creation of the multilevel network the focus is on trade in a specific good which can be characterised as belonging to this sector, and the firms associated in the production of this good. Where the high tech classifications of components were based on those outlined by Lall et al (2006). The medical and precision industry was selected as it has been identified as a sector of importance with further opportunities for several European countries, and in particular to the UK, as it holds a competitive advantage and notable strengths within this sector (BIS, 2010).

High tech industries are of key importance to a nation, for instance when medical device manufacturing plants are established in a country, these have been found to provide additional benefits to the economy as a whole, with positive multiplier effects on employment and output (Callea et al, 2013). Bamber & Gereffi (2013) provide a detailed description and overview of the medical devices industry in their analysis of the position of Costa Rica within this sectors' GVC. They note the industry is extremely concentrated, with a handful of firms accounting for around 40% of the overall market share. The medical devices sector is a heterogeneous industry that is difficult to define, with a large spectrum of sophisticated product lines and no broadly accepted approach for disaggregating the sector; therefore this makes it difficult to make comments which apply to the industry in general (Sturgeon et al, 2013). It is also characterised under a number of different names, such as medical devices, medical technology, and medical and precision; in this general description, the sector is referred to as medical and precision instruments.

The medical and precision instruments industry is also uniquely characterised by specific industry regulations; therefore, the production process is not a tiered system. Rather it is vertically integrated, with many of the production activities taking place in-house, yet not necessarily in the same geographic location. The focus on retaining activities in-house is a result of the regulatory approval for product specifications which are difficult to extend to contract manufacturers. The regulatory diversity across nations has led to many lead firms establishing a presence in multiple end markets, and often acquiring firms mainly for their regulatory certificates (Bamber & Gereffi, 2013; Sturgeon et al, 2013).

Amongst the small number of firms which account for a large portion of the market share is the American giant, Medtronic Inc. This firm specialises in a range of products in the medical devices industry, such as cardiovascular and diagnostic devices. In more recent years, this lead firm has pursued a number of growth strategies, particularly in emerging economies. For instance, in 2012, it devoted numerous resources to the acquisition of the Chinese firm, Kanghui, which is involved in the manufacture of replacement hips. Samsung is also a major firm in the industry, entering the medical devices industry through a number of its subsidiaries; in April 2011, it acquired Medison, a firm based in the Republic of Korea specialising in the production of ultrasound equipment, and has looked into the acquisition of a number of other body scanning firms (The Economist, 2011b).

The US is a major player within this industry for a number of reasons; firstly, it is the world's largest consumer of medical devices, with almost three quarters of sales revenue coming directly from the US (Callea et al, 2013). Also there are a number of clusters and regional hubs located in US that are important to the industry, such as the clusters in Massachusetts, Minnesota (where lead firm Medtronic Inc. was founded), Pennsylvania and California (Kimelberg & Nicoll, 2012). The lead firms within the medical and precision instruments sector are primarily headquartered in the US, and these firms are seen to dominate the market, and even the largest European firms have sizeable operations and investments in the US (Porter et al, 2011).

Europe plays a key role in the medical devices industry, often posing as a launch pad for products before release in the strict regulatory environment of the US. The medical and precision instruments industry is defined by a number of prominent recalls, scandals, and a confusing product approval process in the US. Therefore it is not surprising that these US firms seek other locations to test their products, especially in considering tight regulations outlined by the Food and Drug Administration (The Economist, 2011a). Europe also accounts for a substantial portion of sales of medical instruments (Callea et al, 2013). The UK is a key player in this sector, with a number of small and medium-sized enterprises (SMEs) headquartered in the UK, yet it is the presence of large foreign MNEs that contribute to national employment and has led to the development of the UK's competitive advantage in the sector (Topham, 2003).

Although industrialised nations represent the most important markets, developing nations represent an opportunity for firms in this industry, as demand is beginning to grow, especially in large emerging economies, such as Brazil, India and China (Bamber & Gereffi, 2013).

4. Data & Methodology

This section presents a new multilevel relational dataset created by the author bringing together several secondary sources and explains how the different data were matched. A descriptive analysis of the individual networks is also presented, including geographic mapping of the networks. Furthermore, this section discusses the advanced network model: the Exponential Random Graph Model (ERGM), and its multilevel extension, which is used to answer the research questions addressed by this paper.

4.1. Data

This paper provides a unique contribution in the construction of a novel multilevel dataset to study the patterns that characterise the disintegrated production process in the medical and precision instruments sector. This multilevel dataset provides an improvement on many aspects of existing datasets to map production processes. The use of micro firm data allows to observe the international strategies and investment decisions of multinational groups; a key component in the fragmentation of production that is often not captured through the use of aggregated datasets (Dallas, 2014a). Whilst the use of macro trade data retains a high level of detail, allowing the mapping of production flows in the global economy.

The selection of appropriate data is a key component in investigating the phenomenon of the fragmentation of production and, as this paper utilises a multilevel perspective, matching the data at both levels is essential. This study takes the product as the framing level, considering product trade at the macro and the product production at the micro. The perspective of the product (or function or task, as it has also been referred to) has been argued as more relevant than the aggregated sector level when critically discussing issues in the area of the fragmentation of production (Grossman & Rossi-Hansberg, 2008; Baldwin & Robert-Nicoud, 2014), as a finished product is now generated through trade in intermediate goods (Timmer et al, 2013).

A number of empirical studies have examined the fragmentation of production within MNEs, making use of foreign investment data between firms and their affiliates. However this data has limited coverage and is only available in certain countries, for instance in the US (Hanson et al, 2005) and Germany (Marin & Rousova, 2012). By contrast, the multilevel network approach presented in this paper, making use of a variety of different datasets, can examine how a business group spans its investment across the globe, regardless of the country of origin, and can examine the effects of these investments and ownership patterns on disaggregated trade data and therefore production.

At the country level there are two distinct approaches to map the fragmentation of production; firstly, I-O tables can be used to measure trade in intermediate inputs; the alternative approach is to examine the trade patterns of components with a high level of disaggregation (Srholec, 2006). This study takes the latter approach, making use of highly disaggregated trade data for the year 2012 (at the 5 digit SITC Rev 3 level), extracted from the UN Comtrade database. The sector under examination here is the manufacture of optical and medical instruments; this corresponds to 77421, the manufacture of "x-ray, radiography, or radiotherapy apparatus."

The trade data from UN Comtrade are then used to build the macro level, international trade network, where a tie is directed from the exporter to the importer. A key issue is that ERGMs, and their multilevel extensions, can currently only deal with binary ties, therefore a dichotomisation process must be applied to this data. The dichotomisation threshold applied to the data was that only ties that were at least 0.01% of the value of total trade of 77421 were retained;[16] this threshold ensures that only the most relevant ties were retained yet preserving network structure. This procedure also helped in omitting countries which do not significantly contribute to trade, yet increase levels of reciprocity. The visualisation of this individual trade network can be seen in Appendix A (Fig. 4), where the blue nodes represent countries.

[16] This threshold was determined by examining the proportion of world trade that was retained by applying the threshold, to ensure the network represented the majority of global trade. The 0.01% cut retained 97% of world trade.

In order to ensure the results were consistent, a sensitivity analysis was undertaken, where the estimation process was also conducted for a set of networks in which a 0.1% threshold was applied. Appendix C provides further details on the sensitivity analysis and the impact of the threshold cut applied.

The firm level data was taken from Bureau van Dijk's Orbis database, which provides comprehensive firm level financial and ownership data, in some cases with ten years historic data. This database has been used in the construction of ownership networks in a variety of studies (Glattfelder & Battiston, 2009; Vitali et al, 2011; Vitali & Battiston, 2013), and has been identified as both a relevant and coherent database by a number of scholars (Ribeiro et al, 2010; Fons-Rosen, 2012). In this study, Orbis was used to build the micro level ownership network, along with the firm-country affiliation network. The main issue in the construction of the micro level network was the selection of firms that manufacture the product classification used in the construction of the macro level network. The procedure used to select these initial firms was to identify firms associated with the relevant commodity code, (NACE Rev 2 code 266 - "Manufacture of irradiation, electromedical and electrotherapeutic equipment", as Orbis, does not use SITC Rev 3), so that it can be combined with the trade data for the sector. The next step was to examine the products produced by each firm, (as Orbis provides an overview of production activities of manufacturing firms), removing those who do not fit the sector description, then from this list the ownership network was constructed, linking parents and subsidiaries that are involved in the manufacture of medical and precision instruments.

The micro level network has firms as actors, ties as ownership, directed from the parent firm to the subsidiary. This positional strategy in defining the ownership network boundary ensures that only firms directly occupying a place in the manufacture of medical and precision instruments were included, yet this strategy results in a number of disconnected actors, with a set of small, separate connected components lacking ties between them (Knoke & Yang, 2008). This can be seen in the visualisation of the individual ownership network in Appendix A (Fig. 6), where the ownership network is clearly sparsely connected.

The firm-country affiliation network was then constructed using the Orbis database, making use of further firm level data it provides. The information that was utilised in the construction of this level was the national location information of each of the firm's branches, where they have production, distribution and sales sites. The visualisation of the individual firm-country affiliation network can be seen in Appendix A (Fig. 5).

The full multilevel network therefore contains three types of ties: trade flows between countries, ownership ties between firms and the ties between firms and countries, based on the location of firms. The visualisations of the full multilevel networks can be found in Appendix A (Fig. 7), where red nodes represent firms, and blue nodes countries.[17]

This dataset provides a unique contribution as it overcomes a number of issues with previous datasets to analyse disintegrated production patterns. Firstly, it makes use of highly disaggregated trade data, applying it as a proxy for production, therefore retains the high level of detail bilateral trade data provides (in contrast to I-O data). Secondly, through the combination of micro and macro levels, this dataset allows the investigation of patterns of intra-firm trade, a valuable aspect of the dataset, given data on intra-firm trade is widely unavailable, and then only for certain nations. Furthermore, identifying when trade is characterised as intra-firm can provide additional insights into the investment motives of multinational groups.

4.2. Mapping the Networks

An examination of the network patterns plotted on a geographic map can provide further insights into the geographic distribution of headquarters, investment patterns, and trade.

Ownership Network

Fig. 1 displays the location of firms in the ownership network, on the basis of their headquarters (not their full investment profile), with the nodes coloured by the business group they belong to.

This clearly reflects the structure of the industry, with the majority of firms headquartered in the US and in continental Europe, along with one of the business groups focused on the Scandinavian region (GE Healthcare). The Nordic region seems to play an important role in terms of firm investment and a firm's primary base in this sector. An examination of Nordic/Baltic production networks by Ekholm & Hakkala (2008) provides some

[17]In the remainder of the paper the firm level ownership network is referred to as the micro level, the international trade network as the macro level and the firm-country affiliation network as the meso level, in line with the terminology utilised in multilevel network analysis.

insights; they note that this region is characterised by a relatively compressed wage structure, resulting in the region becoming a destination for offshoring certain production activities. In relation to the medical and precision instruments sector, they note that Sweden has experienced large increases in terms of trade in intermediate goods, which could possibly be a result of an increase in the number of workers with a tertiary education level in the country.

Figure 1 Map of Firm Headquarters

Note: Node colour represents business group membership. Key business groups: Medtroninc – Red, General Electric Healthcare – Orange, Pink – Boston Scientific Corp, Grey – Baxter, Light Blue – Sorin, Blue – Abbott Laboratories, Brown – Fujirebio, White – Isolates in the ownership network.

Firm – Country Affiliation Network

Fig. 2 is the one mode projection of the firm-country affiliation network without its ties, as the full two-mode would have been difficult to interpret when layered over a map. The size of the nodes corresponds to the degree in the meso level, so the number of firms located in each country (whether it is the primary headquarters, directed capital or a production branch). This shows that the production activities in the sector are spread out geographically, yet still could be considered regional to some extent, with a focus on production activities in Europe, with only a limited number of firms based in other regions, such as Sub-Saharan Africa.

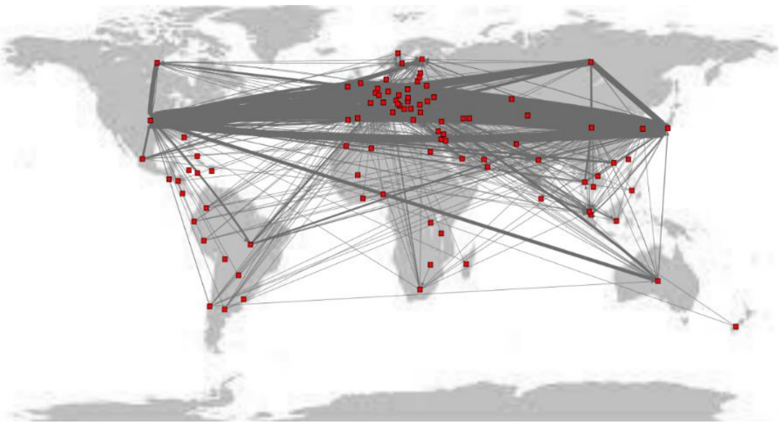
Figure 2 Map of Investment Patterns

Notes: Node size reflects the number of firms with an investment in that country

Trade Network

The mapping of the world trade network displayed in Fig. 3 reveals very little, with patterns better identified through the standard visualisation of the network. This reflects the strong trade ties in Europe and amongst nations characterised as belonging to the global north.

Figure 3 Geographic Map of the International Trade Network



Note: Tie thickness indicates the strength/value of the trade tie

4.3. Descriptive Analysis of the Networks

This section provides an initial descriptive analysis of the networks separately, (in particular the ITN), in order to identify the most prominent firms and nations in the network.[18]

[18] The descriptive network statistics are calculated using a combination of UCINET (Borgatti et al, 2002) and the R packages Statnet (Handcock et al, 2014) and tnet (Opsahl, 2009).

Table 3 provides a summary of the network level statistics for both the (binary) trade and ownership networks. The trade network is characterised by low reciprocity (two way ties), suggesting a hierarchical structure. The trade network is also characterised by a high out-degree centralisation score, which suggests that export ties are not evenly distributed, rather there are a small number of countries with a high number of export ties. The in-degree centralisation score indicates that imports are relatively evenly distributed amongst nations in the network (when compared to exports).

The ownership network is lacking reciprocated ties, transitivity and clustering. This hierarchical relationship is also reflected in the low in-degree centralisation score, indicating each firm only receives a single ownership tie. This result is not unexpected, as by design, the relationship between firms are ownership ties directed from the parent to the affiliate. Kogut & Walker (2001) note that ownership networks are characterised by a low density and are sparsely populated; a characteristic which can be clearly seen in the ownership network. Todeva (2006) further emphasises that ownership networks are often constructed on the basis of hierarchical control.

Table 3 Descriptive Statistics for Trade & Ownership Networks

	Trade Network	**Ownership Network**
Size (No. of Nodes)	95	68
Density	0.0648	0.0105
Reciprocity	0.3247	0
Transitivity	0.4910	0
Average Degree	12.1895	1.4118
Out-Degree Centralization	0.6871	0.2165
In-Degree Centralization	0.1603	0.0046
Clustering Coefficient	0.7319	0

4.3.1. Macro Level – International Trade Network (ITN)

Table 3 indicates a number of further features of the international trade network. The high clustering coefficient of the trade network highlights that it is characterised by areas of high density. The macro network visualisation indicates that the trade network is characterised by a core-periphery structure; Table 4 presents the members of the core along with the core-periphery density matrix and final fitness for the network. The core-periphery structure indicates that the trade within this sector is characterised by a tightly connected group of countries accounting for most of the trade. Where there is clearly a very dense core, with a core-core density score of 0.814. This contrasts to the low periphery-periphery density, which points towards members of the periphery excluded from a high number of trading relationships, dependent on trade with the core. These results indicate a hierarchical structure of international trade, and therefore production, of medical and precision instruments.

Table 4 Core - Periphery Analysis of Trade Network

Core	USA, Germany, China, Japan, Netherlands, UK, Finland, France, Italy Republic of Korea, Spain, Switzerland, Malaysia	**Density Matrix**		C	P	**Final Fitness**	0.789
			C	0.814	0.343		
			P	0.046	0.006		

The core is prominently dominated by European nations, along with the USA, the key areas in terms of demand in the sector. The Republic of Korea's prominent position in the network may be a result of the Korean firm Samsung Electronics and its investment in the medical devices sector as a whole, along with the country's proximity to the related electronics value chain.

While the multilevel ERGM can only deal with binary ties, a descriptive analysis can make use of the weighted ties, so can capture the value of imports and exports. In order to assess a country's importance within the trade network, an examination of the weighted out-degree centrality (as defined by Opsahl et al, 2010) provides a measure to examine the number of trade partners a country exports to and the contribution of these export ties to the total world trade in the sector. The weighted in-degree centrality may be interpreted in the same manner, with respect to the level of country imports.

Table 5 reflects the importance of Germany and the USA in terms of their export performance. The two key countries in the East Asia region are Japan and to a lesser extent China. The import results reflect that USA and Germany are both exporters and importers of intermediate inputs. Furthermore, China is a dominant importer in this sector, perhaps reflecting its high demand for medical devices from its large GDP relative to its domestic production capacity.

Table 5 Country Rankings Based on Weighted Degree Centrality

Weighted Out-Degree Centrality	Weighted In-Degree Centrality
1. Germany	1. China
2. USA	2. USA
3. Japan	3. Russia
4. Netherlands	4. Japan
5. China	5. Germany
6. UK	6. Netherlands
7. France	7. France
8. Finland	8. Canada
9. Italy	9. UK
10. Republic of Korea	10. Australia

The E-I index (see Krackhardt & Stern, 1988 for an overview of the measure) provides an assessment of the degree of regionalisation within the trade network, as it examines the number of external and internal trade ties of a geographic partition. Table 6 indicates the levels of regionalisation within each geographic partition, where a positive score reflects a tendency for inter-regional trade and a negative score intra-regional trade. The group level scores, and overall scores suggests that production in this industry is less regionalised, with a tendency towards a globalised structure. However, as the degree of inter-regional trade is much less what would be expected by chance, this suggests that trade in this sector is still more regional than global.

Table 6 E-I Index for Trade Network

Group level E-I Index	**Internal Ties**	**External Ties**	**Total Ties**	**E-I Index**
East Asia & Pacific	52	152	204	0.49
Europe	236	231	467	-0.011
Europe & Central Asia	2	35	37	0.892
Latin America & Caribbean	0	72	72	1
Middle East & North Africa	2	52	54	0.926
North America	2	74	76	0.947
Oceania	0	15	15	1
South Asia	0	22	22	1
Sub-Saharan Africa	2	21	23	0.826
Network Level E-I Index				
E-I Index:	0.39			
Expected value:	0.645			

The results from the E-I analysis indicates the most important intra-regional trade in the medical and precision sector is based in Europe.

4.3.2. European Trade Network

To further assess the patterns and key players in the area of the network characterised by intra-regional ties, the subnetwork of European nations is considered, along with the weighted ties amongst them.

Table 7 indicates the strong exporting position held by Germany and the Netherlands in Europe. However, there are some noticeable differences when compared to the export ranks of the full ITN. For instance, in the full ITN, the UK is seen to be ranked third out of the European nations based on its export performance, where the UK's export performance is comparable to, (if not slightly better than), France and Italy. However, in the regional network, the UK drops several ranks, with Italy and France clearly outperforming the UK (in terms of exports). This suggests that a large portion of the UK's exports in this sector are outside of the region, contrasting to France and Italy, where exports inside the region are particularly important.

The high level of connections amongst European nations is no surprise; Krings et al (2014) note that trade within Europe has become more integrated in the past two decades. They apply network analysis over traditional techniques, such as trade to GDP ratios, in assessing the level of integration of trade in the region. In their analysis, they highlight that Germany and the Netherlands hold integrated positions, (a feature which can also be seen in the European subnetwork here). They acknowledge that the Netherlands' central position is a result of its trade transit role in the world economy, where it imports large volumes globally and redistributes these across Europe.

Table 7 Country Rankings of European Subnetwork Based on Out-Degree Centrality

Weighted Out-Degree Centrality	Binary Out-Degree Centrality
1. Germany	1. Germany
2. Netherlands	2. Netherlands
3. Italy	3. Finland
4. France	4. Italy
5. Finland	5. France
6. Spain	6. UK
7. UK	7. Switzerland
8. Switzerland	8. Sweden
9. Sweden	9. Spain
10. Hungary	10. Hungary

Germany has a strong performance and a very strong exporting performance of intermediate goods in this sector. Sinn (2006) noted that the German economy is a "bazaar economy", especially in terms of its specialisation in the downstream functions of the production chain, where it expands the value of these stages. However, to do so it must import more and more intermediate products, which are immediately exported after reprocessing. Sinn (2006: 1167) goes on to describe Germany as a "continuous flow water heater for manufactured goods", referring to the scenario of goods in one country going to another, passing through Germany (and German statistics). Marin (2011) discusses this issue, noting that Germany's high export level and perceived competitiveness is a result of increased offshoring of German firms, especially to Eastern Europe, combined with a high level of foreign sourcing of intermediate goods in order to aid in keeping German output prices reasonable in the face of wage constraints in the nation.

4.3.3. Meso Level – Firm-Country Affiliation Network

In addition to analysing the centrality patterns of the trade network, the centrality of the meso level network is also considered. In terms of this firm-country affiliation network, the centrality of a country refers to the number of firms invested in the nation. Whereas the centrality of a firm in the two-mode network refers to the number of nations the firm has a presence in. The most central countries, (to an extent), match those with high weighted out-degree centrality, and those at the core of the trade network (as indicated by the results presented in Table 8). The meso level network is also characterised by a number of isolates (51), where a firm does not have a branch or base of operations within that nation, yet it is present in the trade network. These nations were primarily those who held peripheral positions in the ITN. The most geographically spread firms have a clear link to US headquartered lead firms, especially in the case of the Medtronic business group, which has a number of global firms in the group.

Table 8 Centrality of Firms and Countries in the Meso Level

Countries Ranked by Degree Centrality in the Meso Level (Top 10)	Firms Ranked by Degree Centrality in the Meso Level (Top 5)
1. USA 2. France 3. Japan 4. UK 5. Germany 6. China 7. Italy 8. Canada 9. Australia 10. Norway	1. Medtronic Inc 2. Baxter 3. Medtronic Sofamor Danek USA, Inc. 4. Abbott Laboratories 5. Lumenis Ltd.

4.4. Multilevel Network Analysis – Models & Methods

Models for multilevel network analysis have only really become available relatively recently, and there has now been an influx of interest in them due to rich data sets that can be analysed using these techniques (Lomi et al, 2016; Lazega & Snijders, 2016). The use of multilevel network analysis has been applied to a variety of settings and contexts such as, migration (Brown, 2002), ecological systems (Bodin & Tengö, 2012), delinquent behaviour amongst adolescents (Snijders & Baerveldt, 2003), ego networks (de Miguel Luken & Tranmer, 2010), organisational and management studies (Contractor et al, 2006; Moliterno & Mahony, 2011) and various other contexts. Until recently, the methodological approaches to modelling multilevel networks have been rather limited; often only considering the multilevel network by parts; this has changed since Wang et al (2013) introduced an extension of the Exponential Random Graph Model (ERGM) to the multilevel case, which takes into account both the within and between network ties.

An alternative multilevel model for non-network data is the hierarchical linear model (Snijders & Bosker, 2012). This model considers nested data, focusing on the group affiliation of actors at the micro level. However, this model does not allow for individuals with multiple affiliations to be considered (Mo & Wellman, 2014), a limiting factor in the context of the fragmentation of production, as they would not allow for a firm to be located in multiple countries.

The standard multilevel approach is applied in international business and economics to address a range of topics and research questions. Amongst the most frequently seen are those which utilise a multilevel perspective to analyse the productivity of firms; these argue that firm productivity is not only based on firm characteristics, but also industry and locational features (Nielsen & Nielsen, 2010; Tarziján & Ramirez, 2010; Goldszmidt et al, 2011; Ketelhöhn & Quintanilla, 2012; Giovannetti et al, 2013; Aiello et al, 2013).

A small selection of the literature makes use of a multilevel framework, (not necessarily a robust multilevel model), to examine production patterns in the global economy. Hwang et al (2011) provide a unique contribution in considering vertical specialisation patterns in Northeast Asia; in particular addressing the interplay between vertical specialisation and trade growth. Where vertical specialisation is used as another term for the fragmentation of production, so as production becomes increasing disintegrated, vertical specialisation levels increase.

They make use of a multilevel model (non-relational) in order to illustrate how vertical specialisation shares explain trade growth. At the heart of standard multilevel models is the notion of variance; does the variance between variables at one level explain the variance between variables at another level. In this case, they formulate a two level model in order to assess whether the variance in vertical specialisation shares impacts the variation of trade growth, specifically focusing on Japan, China and Republic of Korea. However, this approach has its limitations, as it assesses the relationship between vertical specialisation and trade growth for a handful of nations separately; neglecting that the fragmentation of production is characterised by a high level of interdependence between nations. The use of a relational multilevel approach provides the opportunity to assess the dependencies between nations in the context of the fragmentation of production.

Romero & Tejada (2011) emphasise the value of a multilevel framework to examine the characteristics of production chains. They make use of a multilevel approach combining micro and macro perspectives. They do this by comparing the two levels of analysis, either disaggregating sectoral data from I-O tables and comparing with GVC case studies or by applying a bottom up strategy, where they aggregate GVC case studies to match the macro I-O data. Their work therefore emphasises the need for a multilevel approach to examine production chains and stresses the value of utilising both micro and macro level data. However, it is limited in its empirical approach, as it only provides a comparative framework. Whereas a relational multilevel approach provides a more systemic perspective, clearly linking the micro and macro with a meso level, therefore no changes are needed to the aggregation level of the micro and macro datasets.

In the standard multilevel literature, there is a distinct gap in the studies considering patterns of international trade, investment and the disintegration of production. In the literature, typically the level two, or macro explanatory variables affect a level one, or micro outcome, Although possible to analyse the case where the micro level variable affects a macro outcome; this micro-macro situation has received less attention and development in the statistical literature (Bennink et al, 2013). However, in the case of trade, investment and production patterns, it is decisions and activity at the micro firm level which become aggregated flows (of trade and investment) across countries (at the macro level).

Additionally, there are various reasons why the multilevel network perspective for the analysis of international trade and ownership has not been applied; one is that the advanced methodologies for analysing them have only recently become available. Another possible reason is that the multilevel perspective is often obscured by jargon with competing theoretical frameworks, with micro level approaches having its roots in psychology and macro level analysis with sociological origins (Kozowski & Klein, 2000; Hitt et al, 2007).

Prior to the model introduced by Wang et al (2013), which provides a methodological framework for analysing cross level effects, a large number of studies did not take into account both within and between level ties. A notable exception was Lazega et al (2008), who conducted a multilevel network analysis of elite French cancer researchers and their laboratories; in this study the first level is inter-organisational and the second level is inter-individual. They then examine the overlap between the networks in terms of whether an individual seeks/gives advice to a researcher who belongs to an organisation which has an inter-organizational tie with the laboratory of the researcher seeking/giving advice. They then categorise the amount of overlap to reflect the strategies that actors use. Bellotti (2012) extends the structural approach of Lazega et al (2008) and analyses the system of public funding to physicists in Italy using bipartite networks; going beyond considering the amount of overlap in considering the multilevel structure of the network.

4.5. Exponential Random Graph Models (ERGMs)

ERGMs are applied in many of the studies of multilevel networks (Su et al, 2010; Keegan et al, 2012), however, until relatively recently these models could only be applied by parts, to the micro, macro and bipartite meso networks individually. Wang et al (2013) have proposed an extension of the ERGM to multilevel networks to capture the cross level effects. In this section, a brief outline of ERGMs will be given, along with an overview of the multilevel extension.

The ERGM represents a probability distribution of all possible graphs on a fixed node set; and that the probability of observing a graph is dependent on the local network configurations defined in the model. Therefore in the model a set of network configurations are specified, the parameter estimates then indicate whether these local configurations are observed in the network more or less than expected by chance (Robins et al, 2007).

The generic, uni-partite ERGM has the following form:

$$P(Y = y) = \frac{1}{k(\theta)} \exp(\sum \theta_Q z_Q(y))$$

Where:

Y is the observed uni-partite network
y is a network instance
Q is all the network configuration types
$z_Q(y)$ is the network statistic corresponding to configuration type Q.
θ_Q is the parameter corresponding to configuration type Q.
$k(\theta)$ is the normalizing constant to ensure that the above is a proper probability distribution.

Wang et al (2013) then extended the above in order to apply the ERGM to the multilevel case; where several additional elements are included in order to take into account the multiple networks involved, the macro network (denoted by A), the micro network (denoted by B) and the meso network (denoted by X).

This extension is expressed in the form:

$$P(A = a, B = b, X = x) =$$

$$\frac{1}{k(\theta)} \exp(\sum \theta_Q z_Q(a) + \theta_Q z_Q(x) + \theta_Q z_Q(b) + \theta_Q z_Q(a, x) + \theta_Q z_Q(b, x) + \theta_Q z_Q(a, x, b))$$

Where:
$z_Q(a)$ and $z_Q(b)$ are the within level network statistics for the micro & macro levels.
$z_Q(x)$ is the network statistic for the structural effects in the bipartite meso level.
$z_Q(a, x)$ and $z_Q(b, x)$ are the network statistics for the interactions between the macro and meso level networks and the micro and meso level networks respectively.
$z_Q(a, x, b)$ are the network statistics for the configurations that involve ties from all three networks.

The extension is a probability distribution where the structure of a typical graph is a cumulation of local process at both within and cross levels. The inclusion of the cross level configurations reflects a clear improvement on previous applications of ERGMs by parts to the individual networks.

The use of this model to the context of international trade and ownership constitutes an improvement on the typical approaches in the analysis of the ITN, which usually provide a descriptive analysis (De Benedictis & Tajoli, 2011; Blázquez & González-Díaz, 2015; Smith & White, 1992), examining aspects such as brokerage, centrality and the degree of nodes (see Robins, 2013 for an introduction to these concepts). Whilst descriptive analysis provides a useful contribution, allowing active and important players to be identified in the network, advanced statistical models, such as ERGMs, allow for a deeper and most robust understanding of network formation and processes.

Many studies examining the ITN focus on aggregated trade flows and, as Srholec (2006) points out, aggregated data can hide important triangular patterns between countries. By contrast, a network analysis of highly disaggregated trade data can allow for further insights, including the nature of intra-industry trade. This paper utilises disaggregated and directed trade data, improving upon a number of previous studies (Snyder & Kick, 1979; Fagiolo et al, 2007). However, this study requires the trade and ownership linkages to be dichotomized, as multilevel ERGMs can only deal with binary data. Nevertheless, this approach still provides a novel and complex analysis of the structure and patterns of international trade and investment.

5. Multilevel ERGM

Whilst the descriptive, exploratory analysis identified central players in the ITN, it does not help identify investment and trade patterns which characterise the medical and precision instruments sector. The multilevel ERGM provides a means to test for specific cross level parameters to identify the types of investment and trade configurations that characterise production of this component group. In the multilevel estimation, a number of initial parameters were fixed; the structure of the ownership network was fixed, as this is the variable used to explain trade and investment patterns in the sector.[19]

[19] Further configurations that were fixed in the network were those which were not observed or considered impossible. For instance, the presence of isolated firms in the meso level, as this would suggest a firm is not located or affiliated with any country, therefore this configuration is considered impossible.

5.1. Network Configurations

Local network configurations are an important part of ERGMs; they consist of a small subset of nodes and ties, which can represent a theoretical process, the model can then test the propensity for this theoretical process in the observed network. These local configurations represent the interdependencies between ties, and in the multilevel case, between levels. As noted by Zappa & Lomi (2015) in their detailed description of an empirical multilevel ERGM, typical statistical approaches often fail to capture these dependencies or treat them as part of the error term.

The structural statistics include a number of configurations at different levels; the macro level, the covariates (at the macro level), the meso level and the cross level configurations. The macro level covariate configurations capture the characteristics of connected actors, so in the case of international trade, capture for instance the GDP or regional partition membership of nations that trade.

As the application of ERGMs in the context of international trade and investment is limited, there is a need to first specify the configurations at different levels, and to clearly note their definition in economic terms, and the theoretical process they represent. Starting with the covariate configurations, then the macro level, the meso level and finally the cross level configurations.

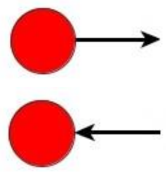
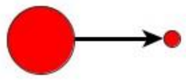
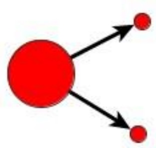
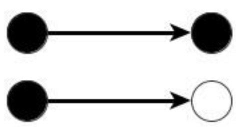
5.1.1. Covariate Configurations

Within the multilevel ERGM, a number of covariate configurations are specified at the macro trade level in order to capture the characteristics of nations involved in bilateral trade ties. These configurations are presented in Table 9, (where GDP is used to illustrate the economic interpretation of the continuous covariates). The covariates included are GDP (nation size), GDP per capita (market affluence) and regional partition. The first two are continuous attributes, therefore the available configurations differ to the categorical attribute of regional partition.

For the continuous attribute, covariate sender/receiver configurations represent the propensity for actors with larger attributes to send or receive ties. Therefore, in the case of GDP, these configurations test whether larger nations are more likely to export or import. A further set of configurations capture the relationship between two connected actors' attributes; covariate sum/difference/product. These configurations allow to test different functions of the attribute values of the actors and their propensity to form a tie. For instance, a positive sum effect for GDP would indicate that larger countries are more likely to trade with each other (similar to the typical gravity model approach). A positive difference effect for GDP would indicate that nations of different size are more likely to trade. An out two-star parameter for continuous covariates is also available, which captures the propensity for a larger nation (in the case of GDP covariate) to have two export ties.

The categorical attributes have a small set of configurations, specifically covariate match/mismatch. In terms of the regional partition the match configuration allows to test for whether trade ties amongst the same regional partition are more likely (intra-regional trade), whilst mismatch would test for the propensity of inter-regional trade.

Table 9 ERGM Covariate Configurations

Configuration	Representation	Economic Interpretation
Covariate Sender/Receiver		GDP: Sender – Propensity for larger nations to export Receiver – Propensity for larger nations to import.
Covariate Sum/Difference/Product	 SUM (+) DIFFERENCE (-) PRODUCT (x)	The likelihood of a tie is a function of the attribute values of the countries involved in the dyad. GDP: Sum – Propensity for larger nations to trade. Difference – Propensity for nations of different size to trade. Product – Trade between two nations is a function of their size.
Covariate Out2Star		GDP: Propensity for larger nations to have two export ties.
Covariate Match/Mismatch		Regional Partition: Match – Intra-Regional Trade Mismatch – Inter-Regional trade

5.1.2. Macro Level Configurations

To model international trade, a number of configurations that correspond to the international trading patterns of nations are specified, (which only apply to the single macro level). These configurations are outlined in Table 10, with the visualisations and qualitative interpretations.

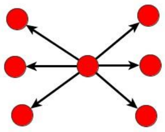
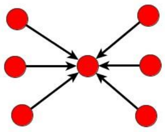
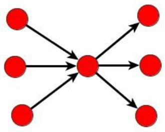
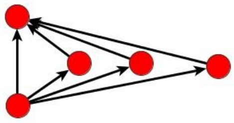
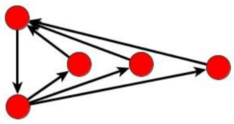
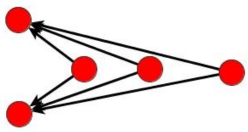
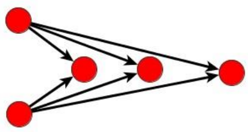
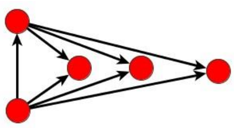
The reciprocity parameter tests the likelihood that nations in the network both import and export from one another. The sink parameter captures the propensity for a nation to import, but not to export.

Recently, there has been an increased interest in whether trade exhibits preferential patterns, where trade is concentrated in a handful of nations. Cingolani et al (2015) make use of complex network analysis, employing a pattern detection algorithm to identify groups of countries with the propensity to concentrate their trade amongst a small number of partners. In this paper, spread parameters are used to capture the distribution of exports and imports in the network and whether or not they are evenly distributed. The activity spread parameter reflects the tendency for a few nations in the network to have several export ties to many other nations. Popularity spread reflects the tendency for a handful of nations in the network to import from many other nations.

The in degree – out degree parameter captures the extent to which the in- and out-degree are correlated; in terms of international trade this captures the correlation between imports and exports, which suggests nations that import intermediate inputs also export.

A number of closure configurations exist which allow to test for the propensity for nations to form subgroups in the network. Transitive closure suggests that nations are more likely to trade with nations that they share multiple trading partners; this parameter also captures the tendency for hierarchical trading patterns to be present in the network. Cyclic closure suggests the propensity for (non-reciprocated) trade occurring within a subgroup of nations. A set of configurations exist that enable the researcher to test for shared activity in the network. Shared in-partners/out-partners in the context of international trade allows to test for the case when active nations import or export respectively to common nations. Shared out partners closure captures the propensity of active nations that export to common nations to also trade between themselves.

Table 10 ERGM Macro Level Configurations

Configuration	Representation	Economic Interpretation
Reciprocity		Countries engaged in two-way, reciprocated trade ties. They import and export to each other.
Sink		A country which imports but does not export goods in the sector. (grey arrow represents a missing tie)
Activity Spread		A few nations in the network have several export ties to many other nations.
Popularity Spread		A few nations in the network have several import ties from many other nations.
In degree – Out degree		Captures the extent to which export and imports are correlated.
Transitive Closure		Nations are more likely to trade with nations that they share multiple trading partners.
Cyclic Closure		Propensity for (asymmetrical) trade occurring within a subgroup of nations.
Shared in – partners		Propensity for importing nations to share common import partners.
Shared out – partners		Propensity for active nations to share common export partners.
Shared out – partners closure		Propensity for active nations that export to common partners also trade between themselves

5.1.3. Meso Level Configurations

The multilevel network contains the meso level of firm-country affiliations. The multilevel ERGM is also able to model parameters at this level, identifying prominent affiliation patterns; Table 11 outlines some of the key parameters and their economic interpretation.

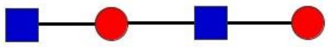
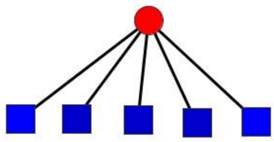
One parameter included captures the different levels of geographic spread of firms; alternating firm star, which captures the propensity for a small number of firms in the network to be linked to a large number of nations. This parameter allows to capture whether there is a centralised structure at the meso level with a few central firms accounting for the majority of firm-country affiliation ties (Wang et al, 2009; Liu et al, 2015).

Another set of parameters that can be specified at the meso level are path parameters. One particular path parameter is the three path; this captures the extent to which two firms are both affiliated with the same country and at the same time, two countries are both affiliated with the same firm. This parameter also allows to capture the geographic spread of firms, where it captures the propensity for firms to locate in countries with many investors (and to link to other firms indirectly).[20]

A further parameter considered in the meso level in order to explain the structure of the firm-country affiliation network is isolated nations. This parameter would account for nations which play a role in the trade network, yet where no firms in the ownership network are affiliated with them.

[20] This interpretation of the three path is in line with the empirical literature applying ERGMs to bipartite networks (including Koskinen & Edling, 2012; Niekamp et al, 2013).

Table 11 ERGM Meso Level Configurations

Configuration	Representation	Economic Interpretation
Three Path		Propensity for firms to locate in nations with many investors (and to link to other firms indirectly)
Alternating Firm Star		Propensity for a small number of firms in the network to be linked to a large number of nations.
Country Isolates		Propensity for isolated nations in the meso level. Nations that are present in the ITN, but do not have an affiliation tie with a firm.

Note: Red circles are firms and blue rectangles are nations. Ties are firm-country affiliation.

5.1.4. Multilevel Configurations

Higher order cross level configurations are a fundamental element of relational multilevel modelling; these configurations involve the trade ties between nations, the firm-country affiliation ties and the ownership ties amongst firms. These configurations are outlined in Table 12, along with their economic interpretation.

Alternating – affiliation based closure tests whether countries are more likely to trade with countries where multiple firms are based in both nations; where a set of firms based in these two nations triggers a trade tie. The affiliation based trading parameter allows to test whether there is a propensity for two nations with a large number of firm affiliations to trade. Affiliation based popularity/activity effects allow to test whether countries with a high level of investment have numerous import or export ties respectively in the ITN.

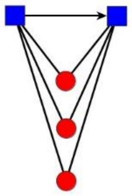
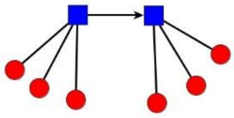
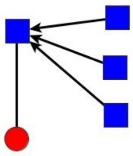
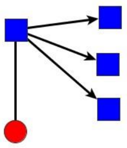
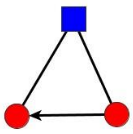
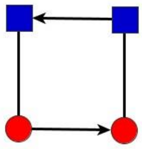
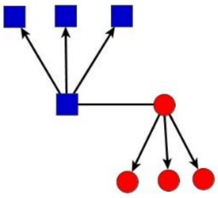
There is also the possibility to test for whether there is a tendency for domestic subsidiaries, this parameter captures whether two firms linked by ownership are affiliated with the same nation.

The intra-firm trade parameter presents a form of cross level exchange; here the assumption is made that the parent and subsidiary ties within this configuration implies that these two firms trade.[21] A further cross level parameter captures the tendency for a nation to establish multiple export ties when a lead firm in located in the nation; where the lead firm is defined as an enterprise with a high number of subsidiaries (as observed

[21] Within the intra-firm trade configuration, trade flows from the affiliate to the parent firm.

in the ownership network presented in Fig. 6).

Table 12 Multilevel ERGM - Cross Level Configurations

Configuration	Representation	Economic Interpretation
Alternating affiliation based closure		Propensity for a set of firms based in two nations to trigger a trade tie between them.
Affiliation based trading		Propensity for nations with high levels of firm investment to trade.
Affiliation based popularity		Propensity for countries with high levels of investment to establish several import ties in the international trade network.
Affiliation based activity		Propensity for countries with high levels of investment to establish several export ties in the international trade network.
Domestic Subsidiary		Propensity for two firms linked by ownership to be based in the same nation i.e. the propensity for domestic subsidiaries.
Intra-firm trade		Propensity for intra-firm trade
Lead Firm Affiliation		Propensity for countries with investment from firms with a high number of subsidiaries (lead firms) to establish several export ties in the international trade network.

Note: Red circles are firms and blue rectangles are nations.

In addition to the parameters presented in Table 12, a number of cross level configurations are included to control for certain characteristics of the micro and meso level networks. These are the subsidiary/parent firm affiliation parameters, which are included to control for the low level of ties in the ownership and meso level networks.

5.2. Model Estimation & Results

All estimation and goodness of fit procedures were conducted with the MPNet software. Zappa & Lomi (2015) provide a detailed overview of the procedures and steps required to gain a well-fitting and convergent model for an empirical multilevel ERGM in MPNet. The model here has a high level of complexity as it attempts to explain the patterns of the trade and investment network, considering only the ownership network as fixed.[22] This is in contrast with extant studies applying multilevel ERGMs, which often consider the micro (or macro) level and the meso level as exogenous (Zappa & Robins, 2016; Brennecke & Rank, 2016), hence reducing the complexity of the model. Three models are presented in this section, the multilevel model, the macro level model (accounting for only trade ties), and the meso level model (accounting for only firm-country affiliation). These three models are presented in order to assess the impact of including multilevel effects on the estimates and overall goodness of fit. In the three models the baseline propensity to form ties, (density), is fixed, and these are all convergent models.

In order to capture the skewed nature of the degree distribution; the case where a few nations in the network constitute a large portion of the trading activity, both spread parameters were included with different λ values, (the additional parameter provides a dampening partner, see for details of this approach).

The results in Table 13 indicate that accounting for higher order cross level configurations does not have a substantial impact on the corresponding estimate parameters or standard errors. However, the inclusion of the cross level configurations provides a model which is better able to reproduce salient features of international trade and investment (see Table 14 and the discussion in subsection 5.3).

The multilevel and macro level models indicate a number of features characterising trade in this high tech sector. Firstly, there is a positive tendency towards reciprocated trade ties in the network, with the odds of observing reciprocated trade ties against observing asymmetric trade ties is ($e^{0.7045}$) = 2.02 in the multilevel model and slightly higher in the macro model, ($e^{0.8192}$) = 2.27.

[22] Within this multilevel ERGM, density is also fixed; density reflects the general propensity for trade and investment ties. These parameters are fixed as the propensity for trade or investment ties to be created is not the primary concern of this paper. Furthermore, this reduces the computational intensity of the model, and to an extent, promotes convergence.

Table 13 Multilevel ERGM Estimates

Effects	ML Estimates (SE)		Macro Estimates (SE)		Meso Estimates (SE)	
Reciprocity	0.7045 (0.338)	*	0.8192 (0.338)	*		
Sink	3.5112 (0.937)	*	3.5331 (0.927)	*		
Popularity Spread 1 (λ= 4)	2.0298 (0.259)	*	2.1209 (0.265)	*		
Activity Spread 1(λ = 6)	0.9387 (0.105)	*	0.9802 (0.108)	*		
Popularity Spread 2 (λ = 2)	-2.5631 (0.758)	*	-2.7336 (0.739)	*		
Activity Spread 2 (λ =1.5)	-3.0592 (0.859)	*	-3.326 (0.854)	*		
In degree – Out degree	1.2332 (0.403)	*	1.1878 (0.419)	*		
Transitive Closure	1.5543 (0.304)	*	1.6166 (0.313)	*		
Cyclic Closure	-0.1183 (0.087)		-0.1128 (0.086)			
Shared out – partners closure	-0.0067 (0.126)		0.0116 (0.115)			
Shared in – partners	0.0087 (0.017)		0.0116 (0.016)			
Shared out – partners	0.06 (0.041)		0.0497 (0.043)			
GDP Sum	0.0513 (0.065)		0.0601 (0.062)			
GDP Product	1.6484 (0.341)	*	1.65 (0.315)	*		
GDP Product Reciprocity	-1.362 (0.372)	*	-1.3563 (0.357)	*		
GDPPC Receiver	-0.3358 (0.073)	*	-0.3385 (0.074)	*		
GDPPC Difference	-0.343 (0.083)	*	-0.3525 (0.086)	*		
GDPPC Out2Star	0.0182 (0.003)	*	0.0189 (0.003)	*		
Region Match	0.1844 (0.138)		0.1889 (0.136)			
Distance	-0.1486 (0.062)	*	-0.1478 (0.064)	*		
Three Path	0.013 (0.002)	*			0.0183 (0.896)	*
Meso Country Isolates	1.8559 (0.486)	*			1.8968 (0.848)	*
Alternating Firm Stars (λ = 4)	0.1416 (0.143)				-0.0514 (0.876)	
Affiliation based activity	-0.2278 (0.06)	*				
Alternating – Affiliation based closure	0.1117 (0.037)	*				
Affiliation based trading	0.0023 (0.001)	*				
Subsidiary Affiliation	-0.2872 (0.113)	*				
Parent Firm Affiliation	-0.3161 (0.095)	*				
Domestic Subsidiary	1.9529 (0.392)	*				
Intra-firm trade	-0.0041 (0.005)					
Lead Firm Affiliation	0.2332 (0.06)	*				

*Note: * indicates a significant effect, where the estimated effects exceed twice the standard error in absolute value. GDPPC is GDP per capita.*

There is a strong and positive sink parameter, indicating the propensity for a number of nations to import goods in this sector, but not to export. This points towards the core-periphery structure of the trade network, with a number of nations in the periphery importing, but contributing very little (or nothing) to exports.

The significant popularity and activity spread parameters (along with their dampening partners) indicates a propensity in the network for imports and exports to be concentrated in a small number of nations. This indicates trade in this network is characterised by a hierarchical structure, suggesting a hierarchical division of labour. The positive and significant in degree – out degree parameter in the multilevel and macro models indicate that import and exports ties are correlated in this sector; therefore, nations that import intermediate inputs are more likely to also be exporters.

The triadic parameters in the network point towards the tendency for hierarchical trading configurations; with the positive and significant transitive closure and negative (yet non-significant) cyclic closure. The remainder of the triadic configurations are non-significant, along with no significant tendency for nations to share export or import partners.

In terms of the network covariates, the GDP sum parameter, which can be interpreted as the typical gravity model parameter for larger nations to trade is non-significant. Rather there is a tendency for trade ties to be a product of the size of the nations involved in the bilateral tie. The GDP per capita results indicate that affluent nations are more likely to have multiple export ties, yet are less likely to be importers in the sector (as illustrated by the different signs of the receiver and out star parameters). This reflects that larger affluent nations often have strong internal value chains, so are able to source inputs domestically rather than importing.

As predicted by the gravity model, distance is seen to have a dampening effect on bilateral trade ties. However, there is not a significant tendency for intra-regional trade; although this indicates that trade is not characterised by a high level of regionalisation, the parameter value is positive, suggesting that trade in this sector is still potentially more regional than global.

The meso level parameters indicate the tendency for firms to locate in nations with a high level of investment, (as indicated by the positive and significant three path parameter). Additionally, the meso country isolate parameters indicates that the firms in the ownership network do not have an investment in all nations participating in international trade at the macro level.

There are a number of significant cross level parameters indicating the association between the ownership ties, and patterns of international trade and investment. The first set of parameters indicate whether there is a tendency for trade patterns based on the affiliation and investment of firms. The negative and significant affiliation based activity suggests that there is a tendency against nations with a high level of investment holding a strong exporting position in the ITN. The positive and significant alternating – affiliation based closure suggests that there is a propensity for a trade tie to be established when a set of firms have a presence in the trading nations. There is only a weak tendency towards highly invested nations trading in the medical and precision sector (0.0023). This result partially reflects the FDI patterns of firms in this sector, suggesting that a notable portion of FDI can be attributed to horizontal FDI. Alternatively, it suggests that heavily invested nations do not represent the majority of trade ties.

The next set of parameters reflect the investment and ownership patterns of firms in the network. The subsidiary and parent affiliation parameters were included chiefly to improve the convergence and fit of the network. The negative results reflect the low density of the ownership network and spread of investment ties amongst firms. The positive and significant domestic subsidiary parameter indicates that this sector is characterised by a tendency for domestic subsidiaries, where business groups share country affiliation.

The lead firm affiliation parameter captures the activity patterns of lead firms with a high number of subsidiaries in the ownership network. In this sector, the positive and significant effect indicates that nations with lead firm investment hold stronger exporting positions in the ITN, suggesting that the activity of lead firms differs from others in the network.

The parameter which is used as a proxy for intra-firm trade in this analysis is non-significant for the medical and precision instruments sector.

5.3. Model Goodness of Fit

The goodness of fit allows to test how well the model is able to reproduce the salient characteristics of the observed network as a whole. In order to compare the ability of the three models, Table 14 presents the partial goodness of fit results for the multilevel, macro and meso level models. The observed column states the number of the characteristics that are present in the observed network, the simulated mean indicates the average number of characteristics that are present in a set of networks simulated by the model, and the t-ratio is used to assess how well the model explains features of the observed network.

Table 14 notes the t-ratio values for the in-degree and out-degree distribution for the trade network and the meso level network, along with the generalised clustering coefficients.[23] The t-ratios indicate how well the model explains the features of the observed network, ideally being closer to zero. Where if the absolute value of the t-ratio is greater than two, then the model is not able to explain or reproduce certain features of the observed network.

The multilevel (ML) model is able to reproduce all features of the network (not just the parameters presented in Table 14), where all statistics have a t-ratio less than two in absolute value. In comparison to the macro level model, the inclusion of higher order cross level effects allows to better capture the distribution of import ties (in-degree) in the trade network, along with the clustering characteristics.

When the fit of the meso level model is compared to multilevel model, it is clear that the inclusion of cross level effects, and the business group affiliation of firms allow to more accurately reproduce the locational choices of firms. The individual meso level model is unable to reproduce the degree distribution of both firms and nations in the network. Table 14 indicates that in order to properly reproduce the characteristics of trade and investment in this high tech sector, higher order cross level effects are required.

[23] The generalised clustering coefficients for the macro and micro levels indicate the ratio between open and closed triads. For the meso level the generalised clustering coefficient represents the ratio between the number of four cycles and three paths (Wang et al, 2013).

Table 14 Goodness of fit for global network properties

Statistics	Observed	ML Model Simulated Mean (SE)	ML Model t-ratio	Macro Level Model Simulated Mean (SE)	Macro Level Model t-ratio	Meso Level Model Simulated Mean (SE)	Meso Level Model t-ratio
Standard Deviation indegree distribution macro level	5.1799	4.9093 (0.394)	0.686	4.5421 (0.357)	1.787		
Skewness indegree distribution macro level	0.8711	0.7212 (0.205)	0.73	0.509 (0.166)	2.175		
Standard Deviation outdegree distribution macro level	14.4001	14.0067 (0.581)	0.677	14.6123 (0.527)	-0.403		
Skewness outdegree distribution macro level	2.7472	2.6967 (0.142)	0.356	2.6433 (0.106)	0.985		
Macro Level Clustering (tm)	0.4911	0.4957 (0.03)	-0.153	0.535 (0.026)	-1.668		
Macro Level Clustering (cm)	0.2454	0.2669 (0.022)	-0.974	0.2433 (0.021)	0.098		
Macro Level Clustering (ti)	0.7111	0.7317 (0.046)	-0.446	0.7813 (0.038)	-1.849		
Macro Level Clustering (to)	0.1734	0.1791 (0.017)	-0.33	0.1666 (0.015)	0.446		
Standard Deviation country degree distribution meso level	4.9183	4.6862 (0.429)	0.541			4.6253 (0.65)	0.451
Skewness country Degree distribution meso level	4.239	3.5208 (0.673)	1.067			2.3225 (0.465)	4.125
Standard Deviation firm degree distribution meso level	5.1076	4.7614 (0.367)	0.942			4.5013 (0.486)	1.247
Skewness firm degree distribution meso level	4.5724	4.4237 (0.542)	0.274			2.4018 (0.776)	2.797
Meso Level Clustering	0.2232	0.227 (0.029)	-0.128			0.3912 (0.097)	-1.738

6. Findings & Policy Implications

The results from the multilevel analysis indicate a number of patterns that characterise international trade and investment (and therefore production) in the medical and precision instruments sector. The model results for the cross level configurations (involving both firms and nations), provide a number of insights into the organisation of production in this sector, along with answers to the research questions outlined in section two.

The first research question asked by this paper was to what extent is the structure of international trade and investment in the medical and precision instruments industry shaped by the relations that link firms together into business groups? The cross level configuration results presented in Table 13 contribute in answering this question, highlighting the complex interplay between micro firm activity and macro trade patterns.

In particular, this is demonstrated by the positive and significant alternating affiliation based closure parameter presented in Table 13. This result indicates that a set of firms based in two nations triggers a trade tie between them. This result suggests that in this sector, trade and investment are highly interdependent, as observed in the literature, where multinational groups contribute a high level towards global trade (UNCTAD, 2013).

A further important research question asked by this paper was to what extent is the medical and precision sector characterised by intra-firm trade? The multilevel ERGM applied to this novel dataset provides the unique opportunity to test for intra-firm trade in this sector for the entire global economy, going beyond the single country level approaches seen in the literature (De Backer & Yamano, 2012), and allows to address this research question. The cross level intra-firm trade parameter presented in Table 13 is non-significant, this indicates that in the medical and precision instruments sector trade is not significantly characterised as intra-firm. This suggests that this sector is characterised by a number of features highlighted by Ramondo (2014); more specifically it points towards the tendency for foreign affiliates of multinationals to sell their outputs for processing exclusively in the domestic market. Furthermore, this suggests that in this sector, vertical ownership does not promote the tendency for intra-firm exchange of goods, rather potentially promotes the use of effective intra-firm exchanges of intangible inputs (Atalay et al, 2014; Ramondo et al, 2016); an important feature to help meet regulatory requirements in a sector characterised by sophisticated product lines.

This paper also asked what types of FDI characterise investment flows in the sector? A number of cross level parameters in Table 13 inform on FDI patterns in this sector. In Table 13, the non-significant intra-firm trade result, along with the tendency against firms locating in a country for exports (negative and significant affiliation based activity parameter), provides a number of insights about the FDI patterns in this sector. Whether there is a tendency for intra-firm trade (of intermediate goods) provides some indication of the motives for FDI (as outlined by Ivarsson & Johnsson, 2000), therefore addresses the third research question.

These results suggest that FDI is chiefly market seeking and strategic asset seeking in this sector (Lanz & Miroudot, 2011). A propensity for market seeking FDI suggests that FDI is often characterised as horizontal, with subsidiaries serving end markets, reflecting the diversity of the medical and precision instruments sector, with countries with varying regulatory systems that require unique product customisation.

Strategic asset seeking FDI allows multinational groups to complement their own firm specific capabilities (Ivarsson & Jonsson, 2003). In the case of the medical and precision instruments sector, this reflects the tendency for firms to invest in a country or participate in M&A activity in order to acquire regulatory approval certificates.

The fourth research question asked by this paper is what is the organisational form of business groups in this sector? The cross level parameter results presented in Table 13 address this research question. The positive and significant domestic subsidiary result informs on the organisational form of business groups in this sector, in particular that there is a tendency for domestic subsidiaries in the sector. This result potentially reflects the importance of domestic value chains in the sector, especially in large, industrialised nations with mature markets.

The final research question asked by this paper was what roles do lead firms play in this sector? The GVC literature highlights the importance of lead firms as key players in the production process in high tech sectors (Bamber & Gereffi, 2013; Sturgeon et al, 2013). The positive and significant lead firm affiliation parameter in Table 13 indicates that there is a tendency for lead firms (with a large number of subsidiaries) to be located in a country for multiple exports. This results confirms that lead firms play a significant role in the medical and precision instruments sector.

The results also provide several insights regarding the characteristics of international trade in the sector. Firstly, the covariate configuration results present a number of patterns regarding regional trade in this sector. Where the distance parameter in Table 13 is negative and significant, whilst the region match parameter is positive (0.1844), yet not significant. These results highlight that distance has a negative impact on trade, yet is not significantly organised around regional blocs. One reason for this is that there is a tendency for strong intra-regional trade in Europe, yet trade appears to be inter-regional elsewhere (as indicated by the E-I analysis). The covariate results (specifically the GDP per capita parameters) indicate that more affluent nations are more likely to export than import, as large affluent nations (such as Japan and USA) have strong internal value chains, and are less likely to import intermediate inputs, yet are key exporters (UNCTAD, 2013).

The activity and popular spread parameters presented in Table 13 indicate that export and import ties are high skewed, concentrated in a small number of nations. This reflects that production is characterised by a hierarchical division of labour, along with that only a small number of mature markets account for a high level of demand in the sector.

The drivers of international production partly depend on country specific features, but ultimately depend on the characteristics of domestic firms (Navaretti et al, 2010). From a policy perspective, actions to improve a country's international performance should not disregard their involvement in complex global operations. At the sector level, understanding firm's international strategies provides a crucial first step towards understanding the drivers of the sector's international competitiveness. The multilevel network analysis has provided an insight into the international operations of firms in this sector, specifically providing an indication of the motives for FDI, and whether trade is intra-firm.

In order for governments to better implement industrial strategies that promote the growth of manufacturing and production, there is a need to focus on areas of notable strength for the nation, and to identify the ownership, investment and trade patterns which characterise this industry. The findings from the multilevel ERGM indicate that lead firms play an active role in the medical and precision instruments sector, which is consistent with the GVC literature on the sector (Bamber & Gereffi). This suggests that in this industry, a policy goal should be to maintain and enhance linkages to key lead firms. Dallas (2014b) notes that in a fragmented production process, policy should aim to develop and cultivate ties to lead firms in a sector through improving internal operations of domestic suppliers and firm innovation systems.

In this sector, trade is concentrated in a handful of nations, reflecting that the majority of demand in the industry is concentrated in a small number of affluent and mature markets. This suggests that there is an opportunity for emerging markets to enter, and better integrate into the medical and precision instruments production network. As the motives for FDI are market and strategic asset based, this would suggest that in order to better integrate into the production process, there is a need for interagency corporation (Sturgeon et al, 2013); streamlining decision and coordinating action amongst policy makers, industry regulators, and private firms (such as insurers with their own set of procedural standards). This effort could also be made at the regional level, as seen in

Europe, where the CE[24] approval process has streamlined production, where the CE mark indicates that a product is ready for the European market. Furthermore, in the US, the FDA often require a product to have a CE mark as a baseline when entering the long and complex regulatory approval process.

7. Concluding Comments

Changes in the global economy have resulted in a shift in patterns of international trade, investment and production, where in order to better understand these patterns, there is a need for alternative datasets and methodological approaches (Helpman, 2006). This paper makes an original contribution to the fragmentation of production literature, making use of an empirical relational approach, rather than applying the network concept as a metaphor. This paper has proposed an alternative modelling approach to consider the fragmentation of production, along with a dataset that can inform on patterns of intra-firm trade, regionalisation, FDI patterns and motives.

The use of the multilevel modelling framework and analysis of the relational dataset has provided a detailed description of the trade and investment (and therefore production) patterns characterising the medical and precision instruments industry. More specifically, the application has allowed us to address the research questions outlined in section two. Firstly, the results highlight the interdependence between trade and investment patterns, clearly indicating that trade in the medical and precision instruments sector is shaped by the locational decisions of firms and the ownership ties that link them together into business groups. Secondly, the model identified trade in this sector was not significantly intra-firm; this result provides a number of additional insights into what motivates FDI in this sector (specifically market and asset seeking). Finally, the model provides an assessment of the organisational form of firms and business groups in this sector. Subsidiaries in this sector tend to be domestic rather than foreign, and lead firms act in a significantly different way to other firms in this sector.

This multilevel ERGM has shown that cross level effects must be included to better explain investment patterns (as indicated by the goodness of fit), along with

[24] CE is an abbreviation of French phrase ‘Conformité Européene’ which translates to ‘European Conformity’.

characteristics of international trade. The inclusion of cross level effects provides an indication of a number of characteristics of the sector.

Although there are limitations to the modelling approach presented here, the paper demonstrates the value of the framework, and the ability to combine firm and country level data to better explain international trade and investment patterns that characterise production in a high tech sector, along with the geographic composition of parent and subsidiary firms involved in the production process. The limitations of the current multilevel ERGM are discussed by Zappa & Lomi (2015), and are mainly concerned with the models' inability to deal with weighted ties and longitudinal data. In terms of a weighted analysis, in this paper a sufficient cut (at the macro level) has been taken to consider the majority of world trade, yet to limit the inclusion of ties and nations which would not significantly contribute to international trade, yet would increase levels of reciprocity. Despite these limits, this paper has provided a framework in which to combine various data sources and model this data in order to make inferences on the patterns of production as they are today.

There are a number of avenues for future research, specifically the extension of the multilevel model and dataset to other sectors. More specifically there is scope to apply this approach to sectors of various technological content, such as medium (automotive) or low (furniture) tech industries. This would allow for a detailed comparison between technological content and patterns of intra-firm trade and FDI motives in the global economy.

Appendix

Appendix A – Network Visualisations

Figure 4 Macro Level International Trade Network

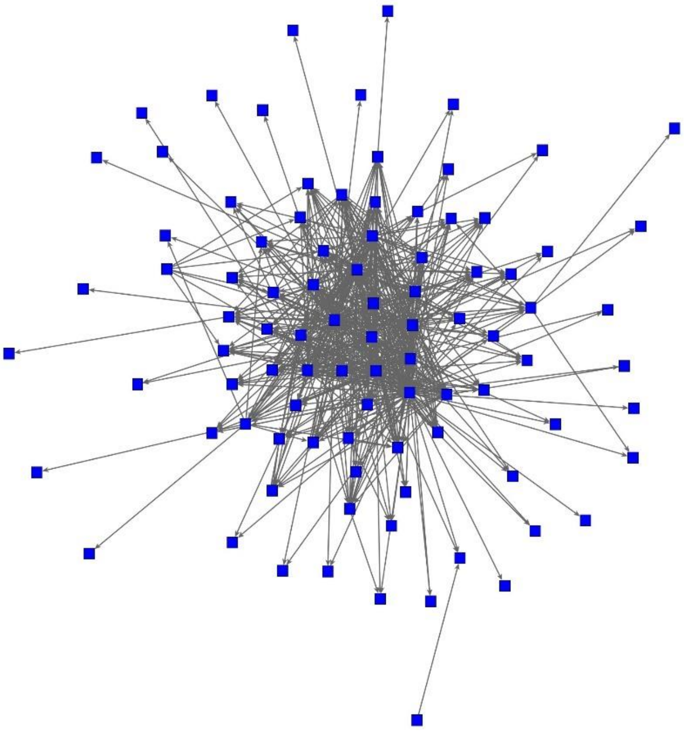
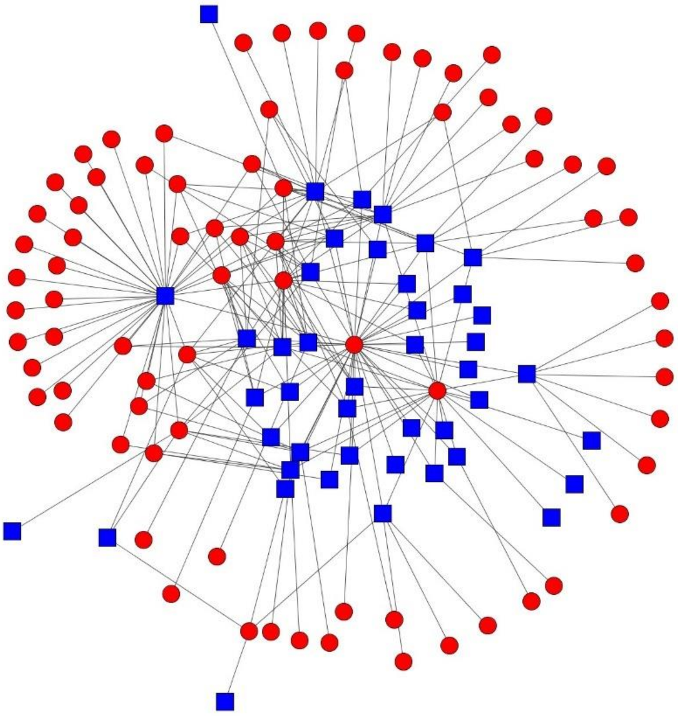
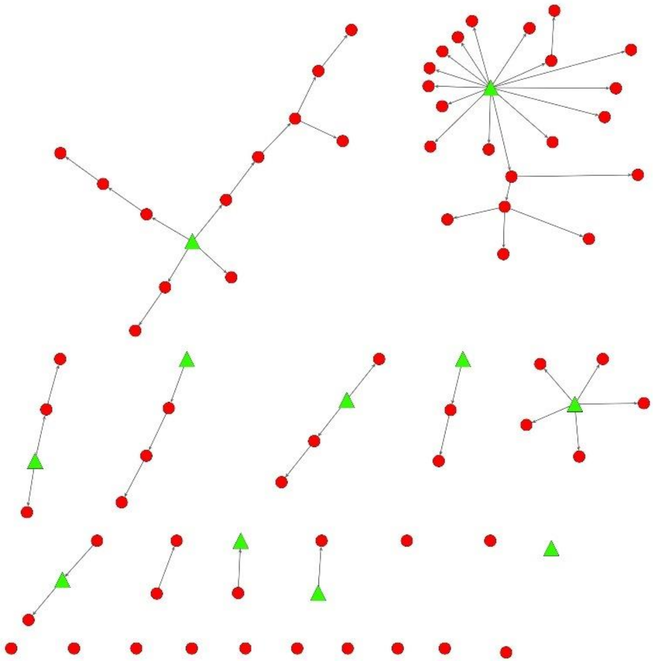


Figure 5 Meso Level Firm-Country Affiliation Network



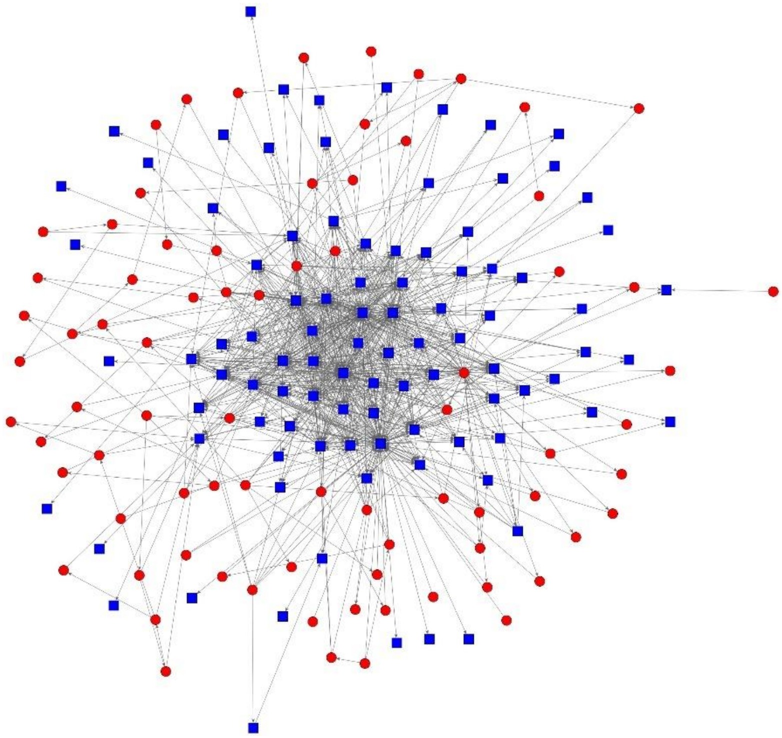
Note: Blue squares are countries and red circles are firms. 51 isolated nations omitted from the visualisation.

Figure 6 Micro Level Ownership Network



Note: Green triangles represent key lead firms in the network

Figure 7 Full Multilevel Network



Note: Blue squares are countries and red circles are firms

Appendix B - Longitudinal Analysis

One of the limitations of the current multilevel ERGM is that it is only able to deal with cross sectional data. Although the multilevel dataset presented in this paper is only for a single year (2012), for the macro level there is a substantial amount of longitudinal trade data available, stretching back to the 1960's. Therefore, in this appendix, some descriptive network statistics are presented for four additional time points (1996, 2000, 2004 and 2008) for the international trade networks (which can be found in Table 15).

In terms of the descriptive metrics, such as reciprocity and the centralisation scores, these have remained constant across time points. The centralisation scores suggest that exports have consistently been concentrated in a handful of nations since 1996. The core-periphery analysis indicates that the network has had a core-periphery structure since 1996, with the core becoming increasingly connected. The centralisation scores and core-periphery analysis indicate that this sector has long been characterised by a hierarchical structure, pointing towards a hierarchical division of labour.

In terms of the weighted centrality scores, these indicate that Germany, USA, Japan and a number of European nations have held positions as major exporters since 1996. The results indicate the rise of China, both as an exporter and importer, where it has increased its export role since 2000. The increased value of imports of the nation may reflect its increased need for intermediate inputs for export, or may reflect the growing demand for medical and precision instruments in the region.

Table 15 Descriptive Statistics for International Trade Networks 1996-2008

	1996	2000	2004	2008
Network Size	82	102	97	100
Density	0.0710	0.0520	0.0580	0.060
Reciprocity	0.3319	0.3102	0.2825	0.3114
Out-degree Centralisation	0.7282	0.6274	0.6890	0.7355
In-degree Centralisation	0.1533	0.1775	0.1627	0.1411
Weighted Out-degree Centrality (Top Ten)	1. Germany 2. USA 3. Japan 4. Netherlands 5. France 6. UK 7. Sweden 8. Israel 9. Italy 10. Belgium – Luxembourg	1. Germany 2. USA 3. Japan 4. Netherlands 5. France 6. Israel 7. UK 8. Finland 9. China 10. Italy	1. Germany 2. USA 3. Japan 4. Netherlands 5. France 6. Israel 7. UK 8. Italy 9. China 10. Finland	1. Germany 2. USA 3. Japan 4. Netherlands 5. France 6. China 7. Finland 8. UK 9. Italy 10. Israel
Weighted In-degree Centrality (Top Ten)	1. Germany 2. Japan 3. Netherlands 4. USA 5. France 6. Sweden 7. Belgium – Luxembourg 8. UK 9. Italy 10. Israel	1. Germany 2. Japan 3. Netherlands 4. USA 5. Israel 6. France 7. UK 8. China 9. Austria 10. Sweden	1. Germany 2. Netherlands 3. Japan 4. USA 5. France 6. Israel 7. Finland 8. UK 9. Malaysia 10. China	1. Germany 2. Netherlands 3. Japan 4. France 5. USA 6. China 7. Israel 8. Finland 9. Italy 10. UK
Core	Germany, Japan, Netherlands, USA, France, Sweden, Belgium-Luxembourg, UK, Italy, Israel, Finland, China, Spain, Switzerland, Republic of Korea, Canada, Russia	Germany, Japan, Netherlands, USA, Israel, France, UK, China, Sweden, Finland, Switzerland, Italy, India, Spain, Canada, Belgium	Germany, Netherlands, Japan, USA, France, Israel, Finland, UK, China, Italy, Switzerland, Spain, Republic of Korea	Germany, Netherlands, Japan, France, USA, China, Israel, Finland, Italy, UK, Spain, Switzerland, Malaysia, Republic of Korea, Belgium, Sweden
Core Density	0.669	0.721	0.788	0.750
Core-periphery Final Fitness	0.771	0.773	0.786	0.806

Appendix C - Sensitivity Analysis

A further limitation of the ERGM when applied to international trade data is that it is only able to handle binary ties; therefore, a threshold is applied. In order to establish that the threshold is correct, and that the estimation results are not subject to substantial change when a stricter threshold is applied, a sensitivity analysis was undertaken.

The threshold applied to the international trade network retained trade ties that were at least 0.01% of total trade. This threshold retained 97% of total trade, whilst disregarding a number of nations and ties from the network, which contributed to high levels of reciprocity, yet very little to overall trade.

It could be argued that a stricter threshold should be taken; if a 0.05% threshold was taken, this would account for 89% of total trade in the sector, whereas if a 0.1% threshold was applied, this would retain 82% of total trade.

In this sensitivity analysis, the stricter 0.1% threshold is considered. This threshold disregards a large portion of ties which contribute very little to international trade, yet retains the majority of the value of trade in the network, suggesting that the cut does not substantially remove key nations or ties in the network.

A number of alternative strategies exist to select the most important ties to retain in the construction of an international trade network. Zhou et al (2016) present a unique approach; constructing the network on the basis of retaining each nation's top export flow (or top two flows, top five flows etc.). They argue that the value of this approach is that it guarantees the inclusion of all nations in the network and allows to control for the density of the network.

This approach may be useful in constructing an aggregated trade network but it becomes less appropriate when considering a sector trade network. In this case, not all nations play a significant role in the sector and therefore it does not make sense to equally represent them in the network. For instance, the top trade tie of Yemen in the medical and precision sector is not equivalent (or as relevant to the industry) as the top trade tie of Germany. Therefore, the application of a threshold allows for the consideration of the most important nations and valuable trade ties in the sector.

In order to verify that taking a stronger cut off point does not substantially alter the estimation results, a different threshold was applied. Here stronger trade ties were retained, where the multilevel estimation was applied to the network taking a 0.1% cut (in the macro network). The corresponding adjustments were made to the macro and meso level of the dataset. In terms of the meso level this involved changing the isolated nations. In the meso level, isolated nations reflected those which were present in the trade network, yet did not have a firm presence or investment. As the threshold was increased, this reduced the number of nations present in the trade network, so these were no longer isolates in the meso level. However, this cut off meant that there was now a group of nations that had firm investment and were present in the meso level, yet were not connected in the trade network, these then became isolates at the macro level.

Table 16 indicates the descriptive statistics for the 0.1% network cut (using the network without any isolated nations).

Table 16 Descriptive Statistics for International Trade Network (0.1%)

	ITN – 0.1% Cut
Size	40
Density	0.099
Reciprocity	0.3484
Out – Degree Centralisation	0.7495
In – Degree Centralisation	0.2137

The result of the multilevel model on the 0.1% cut is presented in Table 17 and indicates that trade is less hierarchical in this reduced network. The sink parameter has also been omitted as a number of peripheral nations which imported, but did not export are no longer present in the network. Regional trade is not significant in this network, (similar to the 0.01% cut off), and distance is seen to play less of role in tie formation, as it is no longer significant.

The meso level parameters indicate that there is still a number of firms and nations with less connections at the meso level. The number of isolated nations has clearly decreased, as the number of countries in the network has been reduced. The significance and signs of the cross level effects have remained consistent given the higher threshold.

The goodness of fit also indicates that the multilevel model is still able to reproduce all of the salient features of the multilevel network of international trade and investment, as indicated in Table 18.

Table 17 Multilevel ERGM Estimation - 0.1% Threshold

Effects	**ML 0.1 Cut Estimates (SE)**	
Reciprocity	0.054 (0.748)	
Popularity Spread 1 (λ = 4)	2.2348 (0.67)	*
Activity Spread 1(λ = 4)	0.6326 (0.485)	
Popularity Spread 2 (λ = 2)	-2.4347 (1.495)	
Activity Spread 2 (λ =2)	2.0537 (1.384)	
In degree – Out degree	2.2086 (1.183)	
Transitive Closure	0.7586 (0.458)	
Shared out – partners closure	-0.3545 (0.255)	
Shared in – partners	0.0293 (0.053)	
Shared out – partners	0.1545 (0.123)	
GDP Sum	-0.0782 (0.117)	
GDP Product	1.3771 (0.433)	*
GDP Product Reciprocity	-0.4 (0.559)	
GDPPC Receiver	-0.498 (0.202)	*
GDPPC Difference	-0.3683 (0.28)	
GDPPC Out2Star	0.0577 (0.022)	*
Region Match	0.6492 (0.437)	
Distance	-0.0905 (0.195)	
Three Path	0.0134 (0.002)	*
Meso Country Isolates	0.503 (0.562)	
Alternating Firm Stars (λ = 4)	0.2447 (0.14)	
Affiliation based activity	-0.2507 (0.06)	*
Alternating – Affiliation based closure	0.0504 (0.11)	
Affiliation based trading	0.0046 (0.001)	*
Subsidiary Affiliation	-0.3447 (0.12)	*
Parent Firm Affiliation	-0.3363 (0.096)	*
Domestic Subsidiary	2.0786 (0.396)	*
Intra-firm trade	-0.0075 (0.008)	
Lead Firm Affiliation	0.2505 (0.059)	*

*Note: * indicates a significant effect, where the estimated effects exceed twice the standard error in absolute value. GDPPC is GDP per capita.*

Table 18 Goodness of Fit for ML model (0.1% threshold)

Statistics	Observed	Simulated Mean (SE)	t-ratio
Standard Deviation indegree distribution macro level	3.1446	2.9013 (0.829)	0.293
Skewness indegree distribution macro level	1.4036	1.0477 (0.525)	0.678
Standard Deviation outdegree distribution macro level	6.9446	7.0197 (1.251)	-0.06
Skewness outdegree distribution macro level	2.9564	2.9264 (0.524)	0.057
Macro Level Clustering (tm)	0.4504	0.4804 (0.053)	-0.562
Macro Level Clustering (cm)	0.241	0.2722 (0.087)	-0.361
Macro Level Clustering (ti)	0.613	0.6983 (0.15)	-0.567
Macro Level Clustering (to)	0.1753	0.1954 (0.094)	-0.213
Standard Deviation country degree distribution meso level	5.903	5.3227 (0.859)	0.676
Skewness country Degree distribution meso level	3.3942	2.6099 (0.72)	1.089
Standard Deviation firm degree distribution meso level	5.1076	4.8177 (0.445)	0.651
Skewness firm degree distribution meso level	4.5724	4.7211 (0.931)	-0.16
Meso Level Clustering	0.2247	0.2166 (0.057)	0.144

III - The Fragmentation of Production and the Competitiveness of Nations in the Automotive Sector – A Network Approach

1. Introduction

Policy makers have long had concerns over the competitiveness of nations, along with economic performance in prominent industries. In recent decades the nature of these concerns has shifted due to the changes in the way production and trade is structured, particularly the dispersion of production across national boundaries (Lall, 2001). Lower transportation and communication costs have led to production activities geographically spread out into global value chains (GVCs), with a rise in the trade in intermediate goods overtaking trade in final goods (Miroudot et al, 2009; Jones et al, 2005; Helg & Tajoli, 2005; Yeats, 2001).

The first paper of this thesis noted that the world economy has undergone a transformation in recent decades. One of the most prominent changes, with a number of implications for the competitiveness of nations, is the increased activity of MNEs and changes to their organisational form. These include the increased use of international sourcing strategies in the coordination of their global supply chains (Helpman, 2006), where outsourcing business functions in a disintegrated production process is becoming a defining characteristic of the global economy (Grossman & Helpman, 2005).

The globalisation of industries, increased levels of outsourcing and global production sharing have intensified international competition. International production sharing provides the opportunity for developing nations to participate in GVCs; rather than developing capabilities to manufacture a product in its entirety, nations can focus on specialising in certain business functions or slice of the supply chain. Participation in complex supply chain activities can potentially provide a number of economic benefits, such as facilitating market access and capability-building through learning (Bernhardt & Pollak, 2015; Cattaneo et al, 2013; Pietrobelli & Rabellotti, 2007).

The rise of global supply chains has triggered a number of concerns amongst policy makers from developed countries, where there has been a fear of job losses due to international outsourcing activity (Park et al, 2013). For instance, the fragmentation of production has led to many firms from developed nations to increasingly outsource and offshore lower value activities to emerging economies (Baldwin, 2012). This has provided the opportunity for a number of developing countries to participate in the production process, often acting as key suppliers in the global supply chain. The expansion of GVCs across industries has deepened the level of integration of so called emerging giants (such as China and India) in the international division of labour (Curtis & Ciuriak, 2010). For instance, China has become a dominant player, at the centre of East Asian production networks, often acting as global workshop. This has generated further concerns, as many industrialised nations are now facing increasing competition from emerging economies, who are steadily developing capabilities where industrialised nations once held a strong competitive advantage (BIS, 2010; Linares-Navarro et al, 2014).

These changes are particularly evident in the automotive industry, where emerging economies have become key suppliers in the sector (Amighini & Gorgoni, 2014; Blázquez & González-Díaz, 2015). Along with a shift of production activities to emerging economies in this sector, there has also been an increase of internationalisation activities of automakers from developing nations, enhancing their capabilities through a number of high level acquisitions. The financial crisis provided the opportunity for auto firms from developing nations to acquire distressed auto firms from the West (Sturgeon & Van Biesebroeck, 2011). These acquisitions have been particularly evident from Indian and Chinese firms. For instance, in 2010, Geely, a Chinese firm, acquired Ford's Swedish car maker Volvo in a $1.8 billion deal (The Economist, 2010). And in October 2008 includes India's Tata Motors purchased Jaguar and Land Rover from Ford for $2.3 billion (The Economist, 2008).

Globalisation can have a number of economic benefits, such as a positive impact on productivity (Kowalski & Büge, 2013), yet the short term costs of globalisation and international outsourcing, such as plant closures and job losses, are much more visible (OECD, 2008). Therefore, the increased level of integration of emerging economies in the production process is often associated with a negative public opinion towards globalisation (in Western economies). This subsequently often generates calls for protectionist policy from public figures, where political actors are reluctant to be on the wrong side of public opinion regarding trade and globalisation issues (Winslett, 2016).

This is often exacerbated by media portrayals of international trade as a struggle between nations, rather than reconfigurations of supply chains that may actually enhance national competitiveness. This suggests a need for more accurate presentations of these processes.

1.1. Statement of the Problem

Rapid globalisation in past decades and the subsequent reorganisation of production has affected national competitiveness, in terms of how it is viewed, appropriate measurement and the drivers of competitive performance (Biggeri, 2007). For instance, complex international sourcing strategies play an important role within GVCs, where access to intermediate inputs are vital in order to develop a competitive offer of goods (Andersson, 2015). Therefore, access to foreign suppliers can potentially allow for the expansion of exports and to better compete in international markets. This contrasts to the more typical view of national competitiveness, where imports (either intermediate inputs or final goods) are viewed as a source of foreign competition (Cattaneo et al, 2013). However, in order to expand the value added in various stages of production, there is a need to increasingly import a higher level of intermediate inputs. This highlights the need to better explain the performance or competitiveness of a country in a sector characterised by a disintegrated production process.

Given the increased levels of interdependence observed in the organisation of production in the global economy (as noted in the first paper of this thesis), there is a need for a systemic approach to assess national performance in industries characterised by an internationally fragmented production process. Baldone et al (2007) highlight that the reorganisation of production raises the issue of whether typical measures of comparative advantage and traditional approaches to model the determinants of competitiveness are still suitable. They question whether these indices and statistical approaches are still well equipped to provide a sufficient overview of the realities of national performance in the world today. Therefore, traditional approaches and methodologies used to support decision-making on competitiveness issues are potentially inadequate in light of the structural changes that characterise production today. The rise of GVCs presents the need for a new perspective to investigate the competitiveness of nations, as GVCs shape the comparative advantages of countries (Amador & Cabral, 2015).

A typical approach when investigating national competitiveness is to examine the profile of a single country, mapping a competitive index for a product or sector (for example

Havrila & Gunawardana, 2003; Cooper, 2006). Cattaneo et al (2013) highlight that when investigating trade and competitiveness, the single country level is no longer appropriate; that the nature of trade today is complex, and that there is a need to undertake an analysis at the global level. They emphasise that a systemic perspective is necessary, given production no longer takes place in a single location, a country cannot be competitive in isolation, rather it must develop efficient[25] links with other nations.

1.2. Aims & Objectives

This study aims to present an alternative framework to assess the competitiveness of nations in an industry characterised by a fragmented production process: the automotive sector. The automotive sector represents an industry characterised by a high level of fragmentation and is considered an important sector by policy makers in terms of its contribution to the economy and political value. This paper employs a relational modelling approach to better identify the determinants of competitiveness in a complex, disintegrated global supply chain. This relational approach provides a more systemic method to model national competitiveness, as it allow to focus on the impact of network effects on international performance; more specifically the impact of a nation developing efficient linkages and having access to foreign suppliers.

It is argued that network analysis can help provide a systemic and global perspective, assuming interdependencies between countries. This paper makes use of a network perspective, analysing the network of disaggregated trade data, which can be used as a proxy for production (Amighini & Gorgoni, 2014). In terms of international trade, a network is defined as a set of nations, linked by directed trade ties.[26] This work makes use of a longitudinal network model in order to assess the competitiveness patterns of nations on the basis of their position in a network of international trade and the competitiveness of trade partners.

Additionally, the disintegration of production has resulted in a shift in the level of analysis used to examine production patterns. As the supply chain is segmented into various

[25] In this paper, the term "efficient" is applied in line with the GVC literature, as observed in the work of Amador & Cabral (2016), Cattaneo et al (2013) and Werner et al (2014). In these works, efficient linkages describe the effective exchange of intermediate inputs (rather than in economics where the term "efficient" is associated with optimal allocation of resources).

[26] Where a tie from nation i to nation j would indicate that i exports to j. These ties may be considered binary, which would simply indicate the presence or absence of a trade tie, or weighted, where the tie captures the value of trade between the two nations.

functions, where individual components are manufactured in various production sites spread out across the globe, the macro sector approach is no longer suitable (Baldwin & Robert-Nicoud, 2014). Therefore, this paper makes use of the more appropriate product level of analysis, in order to assess the competitiveness of nations in various component groups of the automotive sector.

A number of studies assess the trade competitiveness of countries through comparing global trade shares and export performance indices (such as Ishchukova & Smutka, 2013 examining Russia's agricultural sector and Dieter & Englert, 2007 investigating Germany's timber industry). Although mapping the individual performance patterns of a country is a useful and often insightful task, the approach does have a number of limitations. For instance it does not specifically account for the position of a country in regards to other nations and trading partners (Montalbano & Nenci, 2014). A relational, network approach provides an alternative method to overcome these limits, assuming interdependency between nations, rather than examining performance patterns individually, independent of other countries.

1.3. Contribution & Research Questions

This paper intends to provide a contribution to the literature on international competitiveness, specifically to analyse the competitiveness of nations in a fragmented production process, more specifically the automotive industry.[27] A range of scholars have made attempts to link fragmentation of production to indices capturing the performance of nations (specifically within the GVC framework). However, these are chiefly concerned with comparing indices (such as the revealed comparative advantage) based on export data with world Input-Output (I-O) tables at the aggregate level (Benkovskis & Wörz, 2014; Brakman & Van Marrewijk, 2016; Ceglowski, 2015), rather than addressing the underlying determinants of high performance in a sector characterised by a disintegrated production process.

This paper provides the opportunity to test not only how country characteristics influence the performance of nations, but also how a nation's structural position and linkages to other nations influence its competitive performance in the sector. Kinra & Antai (2010)

[27] In this paper the terms competitiveness and performance interchangeably; it is beyond the scope of this paper to provide a discussion on whether an assessment of export performance is consistent with the notion of competitiveness.

highlight a shift in perspectives when considering the topic of competitiveness, with the increasingly popular usage of the structural paradigm to address the competitiveness phenomena.

This paper asks a number of research questions regarding the structure of international trade and the competitiveness of nations in the automotive sector; a sector with high level of political and economic value, therefore investigating competitiveness patterns in this sector is particularly important.

The automotive industry is considered an example of a global industry, with production sites worldwide, yet a number of features have influenced the geographical structure of the sector and point towards the rise of regional production networks. The high political value of the industry has influenced policy and therefore encouraged automakers to "build where they sell" – encouraging final assembly to take place at the local or regional level (Sturgeon et al, 2009). Furthermore, the varying technological content and types of components involved in production have led to different strategies being employed at different stages of the automotive GVC. For instance, components with high weight to value are often expensive to transport, therefore production of these components is coordinated at the regional level (Athukorala, 2009).

The following research questions arise:

1. To what extent is a country's economic performance in the automotive sector determined by its position in the international trade network?

2. Is the economic performance of a nation in the automotive sector influenced by the performance of its trade partners? Are nations more likely to become competitive if they trade with competitive nations?

3. To what extent does a nation's role at the regional level effect its economic performance in the automotive sector?

The first research question provides the opportunity to assess whether a nation with a particular trading profile is more likely to become competitive. More specifically, this allows for an assessment of the impact of having access to intermediate inputs through foreign suppliers on a nation's competitive performance in automotive sector. The second question provides allows to investigate whether creating efficient linkages to competitive nations affects a country's economic performance in the automotive sector. The third research question considers regional trade patterns in the automotive sector, in particular, whether the position of a nation within its region affects international economic performance in the automotive industry. Given the importance of regional production networks in this sector, this emphasises the need to examine the interplay between the position a country holds in a region and national competitiveness in the automotive industry.

This paper makes use of an advanced network model to answer these research questions; a longitudinal extension of the network autocorrelation model, the Temporal Network Autocorrelation Model (TNAM), which presents a technique to model the performance of nations on the basis of their position in the international trade network (ITN) and country attributes over time.

This paper builds on the work of Amighini & Gorgoni (2014) and their network analysis of the reorganisation of production in the automotive sector. Amighini & Gorgoni (2014) make use of a descriptive analysis of various component networks characterising the automotive sector to address a number of research questions. They provide an assessment of whether production of each component is more regional or global. They utilise the network approach to identify key nations in the production of each component, specifically the rise of emerging economies as suppliers in the industry and the subsequent changes to the structure of the networks.

This paper utilises the same product classifications outlined by Amighini & Gorgoni (2014) to create four network groups in order to utilise the more appropriate component level perspective when investigating a sector characterised by a fragmented production process. These component groups include Electrical parts, Engines, Rubber and Metal components and Miscellaneous parts. This paper extends the approach by Amighini & Gorgoni (2014) by additionally considering the commodities that characterise final goods production; assembly and distribution of final automotive goods differs from parts and components, as the former is constrained by high political sensitivities and assembly still plays a crucial role in the automotive sector (Túry, 2014). The definition of the final goods product group is taken from Blázquez et al (2013).

The paper proceeds as follows: the next section reviews the literature on international competitiveness, including a survey of competitiveness measures utilised in various studies. This is followed by an overview of the automotive sector. Section four then presents the data utilised in constructing the trade network and the performance indicators. Section five outlines the method and model specification applied in this paper. Section six presents the results of the TNAM and directly addresses the research question of to what extent a nation's performance or competitiveness depends upon its position in the ITN. The final sections discuss the results and provide a number of concluding comments.

2. Literature Review

The concept of international competitiveness has attracted considerable scholarly attention in past decades. A number of strands of literature have emerged to tackle the complex topic of international competitiveness; ranging from the development of theoretical frameworks (such as the work of Porter, 1990) to a discussion of whether competitiveness is even a relevant concept in a macroeconomic context (Krugman, 1994; Mulatu, 2016).

The review presented in this section covers a number of areas of the literature concerning international competitiveness. Firstly, given that international competitiveness is an elusive concept (Neary, 2006), a survey of various international competitiveness indices, along with subsequent critiques and developments are presented. Secondly, a brief overview of empirical studies assessing the economic performance of nations, (either from a single country or sectoral perspective) is presented. However, it is not the purpose of this paper to provide an exhaustive review of all determinants of national competitiveness in all settings.[28] Rather this part of the review will highlight the key strategies employed in empirical work examining the trade performance of nations, along with work establishing a link between the fragmentation of production and national competitiveness. Thirdly, a stream of literature investigates the rise of emerging economies, in particular the BRIC economies,[29] and whether they pose a threat to the competitiveness of both industrialised and developing nations. Therefore, a brief overview of the international competitiveness literature studying this phenomenon is

[28] See Delbari et al (2015) for a more in depth review of international competitiveness research, along with the most influential works within the subject area.
[29] Brazil, Russia, India and China

presented. The review will conclude with an examination of the extant literature employing network analysis to investigate the interplay between the position of countries within the ITN and economic growth.

2.1. Survey of National Competitiveness Measures

Policy makers often make use of international competitiveness indices to benchmark economic performance, where these indices allow them to evaluate inadequacies, in order to reallocate resources to strengthen areas and develop capabilities (Lall, 2001). However, measuring the economic performance and competitiveness of a country is a notoriously difficult task, given the range of contexts in which the term can be applied (Reis & Farole, 2012; Fertő & Hubbard, 2003; Waheeduzzaman & Ryans, 1996). There are a number of definitions of international competitiveness; at a broader level, this includes the extent to which all citizens experience a satisfactory and growing standard of living (Tyson, 1992). Alternatively, in purely macroeconomic terms, international competitiveness is often regarded as an exchange rate issue (as highlighted by Huggins & Izushi, 2015 and Mulatu, 2016). Furthermore, the term competiveness if often used interchangeably with concepts such productivity and innovation-driven indicators of performance (Carayannis & Grigoroudis, 2014).

A number of scholars even question the relevance of considering competitiveness at the country level; amongst the most vocal is Krugman (1994).[30] Regardless of the scepticisms concerning national competitiveness, it is unlikely that policy makers will disregard issues of competitiveness and benchmarking the economic performance of nations (Fagerberg et al, 2007). They will continue to ask questions such as why do some countries have a better trading performance than others? What policies should be proposed to improve the relative economic performance of a nation?

A range of composite metrics have been developed to capture the competitiveness of nations (see Reis & Farole, 2012 for an overview of these metrics); one of the most widely applied and utilised by policy makers is the Global Competitiveness Index (GCI) developed by the World Economic Forum (WEF, 2015). This is a broad measure which assesses the competitiveness of nations on the basis of twelve pillars comprising of over a hundred individual components including both macroeconomic and micro business

[30] See Dunning (1995) and Krugman (1995) for further details regarding the debate on whether it is appropriate to discuss competitiveness at the country level.

aspects. These twelve pillars are split into three groups: (i) basic requirements (such as infrastructure), (ii) efficiency enhancers (such as higher education and technological readiness) and (iii) innovation and sophisticated factors. In the formulation of the GCI for a country, the set of pillars within each group are weighted depending on development levels. Where the pillars and components in the first category will receive a higher weight for countries with lower development levels and the third category will be assigned an increased weight for advanced nations with greater development levels (Dusa, 2014).

The work of Porter (1990) provides the underlying theoretical base for the GCI. Porter (1990) introduces a diamond model, which emphasises four interlinked areas influencing the competitiveness of a nation:[31] factor conditions, demand conditions, related and supported industries and firm strategy, structure and rivalry. The approach emphasises that to improve the competitive performance of a nation there is a need to support one of the diamond points in an industry, such as through the use of subsidiaries to firms, tax breaks and educational policies.

Although the diamond approach is frequently applied in empirical studies, and has a broad appeal to policy makers, it has been critiqued and extended by a number of scholars. Amongst the most prominent is the work of Rugman & D'Cruz (1993), noting the original model is not applicable to all nations, in particular small, open economies. A set of further limits have also been recognised; amongst them is the level of analysis. Porter (1990) continually shifts between firms, industries and nations when discussing the conceptualisation of national competitiveness, often focusing on the ability of firms and industries in the "home base" to gain large shares of the global market (Davies & Ellis, 2000). The overlap of conceptual levels with various degrees of disaggregation has resulted in further ambiguity regarding definitions and measurements of competitiveness (Congdon, 1990). A further aspect critiqued is the notion of "home base", which does not necessarily allow the role of FDI to be included within the analysis. Additionally, the rivalry aspect of the diamond model is also focused on the home base (and is rather difficult to fully measure), neglecting that rivalry also exists at the global level when competing in international markets (Wezel & Lomi, 2003). In a globalised world, in order

[31] Hence referring to the model as a "diamond" with four points.

to fully assess national competitiveness, international features must be incorporated into the analytical framework (Cho et al, 2008).

Regardless of the criticisms of the work of Porter (1990), the GCI metric remains popular amongst policy makers. However, the measure itself is also not without controversy and criticism; in particular, Lall (2001) outlines the deficiencies of the measure, specifically its methodological and quantitative weaknesses. In the context of the reorganisation of production, the ability to remain competitive in a certain function or stage of the production network is a more appropriate level of analysis (Athukorala, 2009). Therefore, the composite GCI's relevance in assessing a nation's performance is somewhat limited. Cinicioglu et al (2012) demonstrate that the composite index developed by the WEF is not an ideal measure in the automotive sector; where they identify only 15 of the 111 components of the measure are relevant to the automotive industry.

The Institute for Management Development (IMD) have also developed a competitiveness index, which shares a number of conceptual features with the GCI; it is also composed of a large number of sub-indices based on hard and soft data (IMD, 2012). This leaves the index subject to many of the same criticisms and weaknesses of the GCI; furthermore, it is also limited in term of coverage, where it is only available for 59 countries.[32]

The UN Industrial Development Organisation (UNIDO) have developed a composite index to capture to the industrial performance of nations for cross-country analysis, the Competitive Industrial Performance (CIP) index (UNIDO, 2002). The CIP provides a measure to capture the manufacturing *potential* of nations. It is composed of eight sub-indices, which can be grouped into three categories: firstly, capacity to produce and export manufactures, secondly, technological deepening and thirdly, upgrading and world impact. The function of the CIP index is to provide a tool for identifying potential problem areas, acting as a policy aid when assessing the broad features of the economic system (Andreoni, 2013).

Although these single composite measures of competitiveness attract a number of criticisms, especially regarding whether a single aggregate measure can fully capture the

[32] See Carayannis & Grigoroudis (2014) for a detailed overview of the IMD's measure of competitiveness, the GCI and a number of other competitiveness indicators.

notion of competitiveness across sectors, they still remain popular with policy makers. A single aggregated measure is often preferred in benchmarking exercises.

Along with competitiveness indices developed by international organisations, trade-based measures are often applied to assess a nation's economic performance. Trade has long been used as a measure of national economic performance, with an early definition of national competitiveness given by Scott & Lodge (1985: 3), describing it as "a country's ability to create, produce, distribute and/or service products in international trade while earning rising returns on its resources".

Although the notion of competitiveness is approached as a separate topic in international business and economics, it has its roots in international trade theory.[33] The concept of competitiveness has a strong association with theories of specialisation, such as the classic theory of comparative advantage.[34] Comparative advantage refers to when a nation can produce a good in which the opportunity cost of producing the good is lower in comparison to other nations, therefore this theory is applied to explain patterns of specialisation and trade at the sector level (Ricardo, 1891). However, as there has been a rise in trade in intermediate goods, where offshoring business functions is a common practice in the production process, Grossman & Rossi-Hansberg (2006) note there is a need to move away from typical approaches focusing on final goods. In relation to the notion of competitiveness, Cho & Moon (2000) note that the theory of comparative advantage is somewhat incomplete; it is able to highlight differences in productivity levels between countries, but unable to fully explain why these differences exist.

An alternative theory to explain patterns of specialisation that was developed to complement and build on the theory of comparative advantage is the Heckscher – Ohlin (H-O) theory. The H-O theory notes that differences in national factor endowments, such as labour and capital, determine specialisation and trade patterns (Helpman, 2011). However, the empirical evidence supporting the H-O theory is somewhat mixed, suggesting that factor prices alone do not determine international trade and specialisation patterns (Grimwade, 2003). Furthermore, as production has become increasingly

[33] See Kordalska & Olczyk (2014) for a discussion of the determinants of export performance based on a range of theoretical perspectives and Waheeduzzaman (2011) for an overview of the key conceptual works examining the broad macro aspects of competitiveness.

[34] Siudek & Zawojska (2014) provide an overview of how the concept of competitiveness links to a number of theoretical frameworks.

fragmented, a finished product is not simply the result of the factor endowments of a single nation, rather all those participating in the production process (including those manufacturing intermediate inputs). When examining the performance and specialisation of nations in specific industries, the fragmentation of production has distorted many aspects of the concept of comparative advantage; emphasising the need to complement these theories with alternative approaches to better understand the competitiveness of nations in disintegrated global supply chains (Baldone et al, 2007).

Nevertheless, trade-based measures still provide a number of insights into the global performance of nations. One of the most widely applied measures to capture the trade performance of nations is the Revealed Comparative Advantage (RCA) index, as developed by Balassa (1965). The RCA is a measure which captures the ratio of a nation's export share in a sector compared to the average export share of the sector.

But whilst the RCA captures relative export performance, it can differ greatly from sectoral export performance. Haar (2014) demonstrates that there is a clear discrepancy between the level of exports in a sector and whether a nation holds a comparative advantage; industries where a nation holds a comparative advantage are not necessarily the industries that export large volumes.

Numerous scholars have undertaken research regarding the RCA index, such as its ability to capture the theoretical concept of comparative advantage (Deb & Hauk, 2015) and various transformations applied to improve certain properties of the measure (Amador et al, 2011). For instance, the raw RCA index can be transformed in order to gain an RCA measure with a symmetric distribution in order to ensure the distribution is stable so that values can be compared over time (Laursen, 2015).

Although this measure is frequently applied in empirical studies to assess the competitiveness of a nation, and its performance in a particular sector, there is a need to question the extent to which the RCA is consistent with the notion of competitiveness. The RCA is a relative measurement which captures the performance of a product within a country; whereas the notion of competitiveness (especially in policy terms), requires a cross-country comparison of their performance in a product group (Lafay, 1992). When the RCA is utilised in a cross-country analysis, large differences in the size of nations can result in various issues, such as assigning a higher weighted RCA score to smaller nations.

Furthermore, a number of scholars question whether the RCA is suitable in assessing the performance of nations in a fragmented production process. Amongst them is the assessment of the index by Baldone et al (2007: 1762), where they note that the disintegration of production "blurs the concepts of comparative advantage as we know it".

The calculation of the standard measure of RCA based solely on gross exports, has led to a number of scholars questioning the extent to which a single flow measure can provide an assessment of a nation's performance in international trade. Iapadre (2001) provides an overview of a set of net trade indicators and argues that these are more suitable in defining the performance of nations. However, whether net balance measures are appropriate for assessing performance in a sector characterised by a disintegrated production process is debateable, as they assume imports are a negative effect (Guerrieri & Vergara Caffarelli, 2012). On the other hand, importing intermediates for re-processing and further export is a fundamental element of the global supply chain.

One commonly used, simple net trade measure is the normalised trade balance, which is the ratio of the trade balance of a nation (in an industry) to the nation's total trade (in the industry). However, when examining highly disaggregated trade data the use of this measure may be misleading, given high values (i.e. the extreme), may simply indicate a nation which exports very little, yet does not import. This would suggest a high performance in the industry, yet in reality may simply indicate that it is not a key participant in the sector (Andreoni, 2013).

Vollrath (1991) suggests the need to incorporate imports into the calculation of the RCA, and offers an alternative, the Relative Trade Advantage (RTA). The RTA is the revealed export advantage (RCA) minus the revealed import advantage (RMA)[35] of a country. If the RTA is greater than zero, this indicates that a nation has a relative comparative trade advantage, that is a nation is relatively more competitive in the sector in terms of its trade profile. The RTA is not without criticism; as noted by Vollrath (1991), the RTA shares some of the limitations of the RCA measure, in particular that it is sensitive to small (or non-existent) export or import values.

[35] The RMA is calculated in the same way as the RCA, but for imports.

Bojnec & Fertő (2012) highlight the interdependencies between comparative advantage measures and other (typical) country competitiveness measures. They identify a high level of consistency between the RTA and trade competition indices, such as the trade balance, price competitiveness and the unit value of exports.

A further alternative to the RCA is the Lafay Index (Lafay, 1992), which takes into account both export and import trade flows. This alternative measure complements the RCA in terms of its ability to control for intra-industry trade, by accounting for the difference between export and import flows (the normalised trade balance) in its calculation. Positive Lafay values indicate specialisation whilst a negative value points towards despecialisation patterns (Zaghini, 2005). This index establishes whether a country has a comparative advantage based on trade balance in the sector weighted by a country's overall trade balance. This measure of trade performance has been utilised in a number of studies, amongst them Ferrarini & Scaramozzino (2015) and Alessandrini et al (2011).

Although the RCA and related measures have their limits, they are still widely applied in policy related works (such as Beltramello et al, 2012; BIS, 2012a), due to their intuitive appeal (in terms of interpretation) and straightforward calculation process.

In the context of a sector characterised by a disintegrated production process, the value of trade balance measures to assess performance (such as those outlined in this section) is debateable. In a fragmented production process, a trade surplus is not necessarily superior to a deficit (Haar, 2014). Where in a fragmented production chain, nations often import a high level of intermediate inputs for further reprocessing and export in order to remain competitive and expand on the value of downstream production stages (Cingolani et al, 2015). This suggests that further work is required to develop a measure to better assess performance in sectors characterised by a fragmented global supply chain.

2.2. National Competitiveness Empirical Studies

In this subsection, there is a focus on trade-based measures, given that composite indices such as those developed by the WEF and IMD are not necessarily suitable in the context of a sector characterised by a fragmented production process. As competitiveness is a complex concept, with numerous definitions and indices, the determinants vary widely depending on the setting and measurements employed (Siudek & Zawojska, 2014).

For instance, Delgado et al (2012) argue that competitiveness (defined at the broader level) is shaped by three key factors: social infrastructure, fiscal policy and microeconomic conditions. By contrast, Kordalska & Olczyk (2014) note that export competitiveness is determined by a range of other country characteristics, including levels of demand (both foreign and domestic), trade openness, investment intensity and labour productivity. This highlights that the perspective and measurement of national competitiveness can impact results regarding key determinants.

An approach frequently observed in the literature empirically examining the topic of national competitiveness is to map an index for a single nation over time for multiple or individual sectors, noting how a country's performance in certain industries have improved or weakened. For example, Gnidchenko & Salnikov (2013) map the competitive position of Russia and Havrila & Gunawardana (2003) examine Australia's textile industry over time. The use of a comparative approach rather than statistical modelling arises from the metrics available, as many are not suitable in cross-country analysis, including the RCA, perhaps the most widely used metric for international competitiveness.

The use of the RCA as a comparative tool to examine the national competitiveness of nations is well documented in a number of industries; amongst them the agro food (Fertő & Hubbard, 2003; Bojnec & Fertő, 2009, 2015; Serin & Civan, 2008; Latruffe, 2010) and textile sectors (Chi et al, 2005; Hanif & Jafri, 2008; Lau et al, 2009).

A potentially more fruitful approach to analysing international competitiveness is consideration of the relationship between international inputs and outputs by industry. Timmer et al (2013) describe how the World Input-Output Database (WIOD) can be utilised in measuring the competitive performance of nations, demonstrating its use in analysing Germany's automotive sector. Timmer et al (2014) recognise the value of the RCA concept, in terms of its direct and clear interpretation, and so make use of the WIOD to calculate a nation's RCA of Global Value Chain incomes. A higher value indicates that a nation has a higher share of GVC income in the sector compared to its overall share of GVC income. A number of studies have built on this approach, with Ceglowski (2015) and Brakman & Van Marrewijk (2016) providing a detailed comparison of RCA measures based on Input-Output (I-O) data to those based on gross exports.

The use of GVC incomes provides a novel way to assess the competitiveness of nations participating in global supply chains; nevertheless, it still has a number of limitations. It is limited to the coverage of the I-O datasets, which considers sectors at a high level of aggregation, along with reduced coverage in terms of nations and years (especially when compared to standard international trade datasets). This limit becomes increasingly prominent when examining a sector such as the automotive industry, where the manufacture of the final product contains parts and components with widely differing technological content and production patterns. In a sector characterised by a fragmented production process, investigating the competitiveness and performance of the business function or product grouping is a more relevant and appropriate level of analysis. Timmer et al (2014) acknowledge that there is still much work to be done in terms of improving I-O data, in particular, a higher level of disaggregation is required to consider the heterogeneous trends characterising national competitiveness in manufacturing industries.

The link between the fragmentation of production and export performance has not been fully addressed in empirical studies (Guerrieri & Vergara Caffarelli, 2012). The work based on WIOD is primarily used to demonstrate the value of alternative metrics and datasets, than to fully assess the determinants of performance in a fragmented sector. Nevertheless, some scholars have analysed competitiveness with a link to the reorganisation of the production process. For instance, Athukorala & Waglé (2014) provide an assessment of the export performance of Georgia, noting that increasing involvement in production sharing allows a nation to specialise in certain slices of the production process and subsequently enhance its export performance; they identify that in the case of Georgia, it has not fully exploited the potential benefits associated with integration into global production networks.

Overall, the various empirical studies highlight the complexity and elusive nature of the competitiveness concept, where features of competitive performance are highly dependent on the context where they are applied (in terms of country and sector), and measurements utilised. Moreover, these studies suggest that there is scope to further explore the link between the fragmentation of production and the competitiveness of nations, especially in cross-country analysis.

2.3. The rise of BRICs – a threat to competitiveness?

Although the rise of the emerging economies – more specifically the BRIC nations – is an important topic in the competitiveness debate, it is the rise of China (and to a lesser extent, India) as a dominant player in the global economy that has attracted the most attention (Paul, 2016; Qiu & Zhan, 2016), with many scholars questioning whether it is a threat to the competitive position of both industrialised nations (Vu, 2015) and other emerging economies (Lall et al, 2005; Jenkins & Edwards, 2015).

A number of scholars have dealt with the implications of the rise of China to other developing nations; more specifically its impact for the region (amongst them Lall & Albaladejo, 2004; Greenaway et al, 2008; Amann et al, 2009). Since China's accession to the WTO, it has expanded its export performance in labour intensive goods; this has raised concerns amongst other developing nations with a comparative advantage in these goods (Shafaeddin, 2004). More specifically, does China act as a competitor for other East Asian nations or is it an engine for export growth for its neighbours (Pham et al, 2016)? Nevertheless, this is a question that does not have a clear answer. Several scholars argue that China represents a competitive threat to the export performance of Mexico, along with the Latin American (amongst them Jenkins et al, 2008; Qureshi & Wan, 2008) and the East Asian regions (especially in low tech and resourced based industries); whereas Athukorala (2009) notes that the crowding-out concerns are highly exaggerated.

China's integration into the world economy and improved export performance has led to an increase in interest in the examination of the competitive dynamics of China in a number of sectors (Zhang et al, 2013). The performance of China has been analysed through various perspectives and measurements, such as the RCA (Shafaeddin, 2004; Zhang et al, 2013), the CIP index (Zhao & Zhang, 2007) and the trade balance index (Li et al, 2016). Additionally, a number of sectors have been analysed in further detail, amongst them the wooden furniture industry (Han et al, 2009) and electrical equipment sector (Lu, 2015).

Along with China, a further set of emerging economies have also been discussed, particularly India, focusing on the extent to which they present a challenge to developed economies. Qureshi & Wan (2008) investigate whether China and India act as complementary forces to nations in certain sectors, along with where they are competitors. In their work, they consider nations with a shared RCA in a product to be competitors, noting that China presents a challenge to industrialised nations in medium to high tech products. Montalbano & Nenci (2012, 2014) further analyse RCA patterns to highlight the competitive or complementary nature of the rise of China, India, Brazil and South Africa, noting that amongst these nations, China presents the most prominent challenge to the performance of advanced economies.

2.4. Network Analysis & Economic Growth

There is a great deal of extant literature applying network analysis to analyse the ITN (see the first paper of the thesis for a review); along with a number of studies examining the economic growth of nations from a relational perspective.

One stream of literature that has highlighted and empirically tested the relationship between the economic performance of nations and the position in the ITN, is work of world system theorists employing Social Network Analysis (SNA) techniques (amongst them Snyder & Kick, 1979; Breiger, 1981; Nemeth & Smith, 1985; Smith & White, 1992; Mahutga, 2006; Mahutga & Smith, 2011). These works often test whether there is a process of unequal exchange occurring in the world system (or ITN), where nations in the periphery are excluded from the most profitable activities in the global economy, with wealth (or value) concentrated at the core (Lloyd et al, 2009). This stream of literature has highlighted that nations in the core occupy dominant positions, where nations in the periphery typically hold subordinate roles, constrained or dependent on relations with nations at the core.

Clark & Mahutga (2013) extend the world system hypothesis, testing whether a form of unequal exchange occurs across the core-periphery partitions of the global economy. They apply network analysis to test whether a nation's "trade centrality" can be enhanced or improved by trading with highly connected or isolated partners. They note that trade between nations occupying different positions in the ITN and the gains from these exchanges, are a result in differences in bargaining power; where nations in the core hold more favourable bargaining positions. They conclude that nations gain more from trade and have an increased trade centrality when they are involved in unequal exchanges with isolated trade partners.

A variety of studies outside of the world systems literature have utilised network analysis to investigate the link between the topology of economic networks and the performance of nations, such as economic growth and comparative advantage patterns. Amongst them is the approach formulated by Hidalgo et al (2007) examining the complexity of a nation's export basket and patterns of specialisation of certain products within a network perspective. This is operationalised through the creation of a bipartite network linking a nation to a product if it has a comparative advantage in the manufacture of that product (i.e. if the RCA is greater than or equal to 1). The bipartite network is then projected onto two one-mode networks; a country-to-country network, where nations are linked according to shared specialisation, and a product-to-product network, where products are linked when a country is specialised in both products. The latter provides the opportunity to ask research questions regarding the resulting "product space." For instance, this perspective allows the examination of country upgrading opportunities, as nations tend to upgrade to products that require similar specialisation capabilities (Hidalgo & Hausmann, 2009; Kali et al, 2013). However, while providing an insight into product proximity and specialisation patterns, this does not allow for a consideration of the interplay between trade structure and patterns of performance.

Hidalgo & Hausmann (2009) utilise this relational framework to develop an Economic Complexity Index (ECI), building on the work of Hausmann et al (2006). This measure captures the complexity of a country's export profile, examining whether a country has the capabilities to manufacture complex products. A nation that is able to produce more sophisticated goods is better equipped to compete in a range of markets (Hausmann et al, 2014).

The development of these measures has resulted in a stream of literature devoted to examining the relationship between the complexity of a country's export basket and economic growth. This approach has been utilised to examine the patterns of a number of nations, such as China (Jarreau & Poncet, 2012), the Netherlands (Zaccaria et al, 2015) and Turkey (Erkan & Yildirimci, 2015). Further efforts have been made to extend and assess economic complexity metrics (amongst them Mariani et al, 2015; Cristelli et al, 2013; Tacchella et al, 2012, 2013). However, these approaches focus on the aggregate drivers of economic growth, rather than examining the drivers influencing a nation's ability to compete in a specific sector.

This review highlights the value of a relational approach to assess the economic performance of nations, however, there is scope to build on this work, assessing the extent efficient linkages in the ITN effect competitiveness, and the impact of specific network effects.

3. The Context – the Automotive Sector

The automotive sector is considered an important industry by policy makers, because of its significant contribution to employment, along with its high visibility (Sturgeon & Van Biesebroeck, 2011). The sector is considered of substantial importance, especially to industrialised nations; this is most evident in the US, where the auto sector and supporting industries account for a significant level of private sector jobs (Klier & Rubenstein, 2006). In the US, the sector is not only viewed as an important contributor to economic growth, but also represents a source of national pride, where the dominance of US automakers has been a significant feature of the economic landscape in past decades. During the 2007-2008 financial crisis, US automakers General Motors and Chrysler received a $17.4 billion bailout; reflecting the importance of the sector, and the significant potential political consequences of the demise of a major American industry (Financial Times, 2008; Klier & Rubenstein, 2013).

This sentiment is not limited to the US, many European nations also highly value domestically headquartered automakers; this was demonstrated in France, where the sector received a €6 billion bailout to support Renault and Peugeot-Citroen (Financial Times, 2009). Additionally, in the UK the automotive sector is also of strategic value, where it employs around 129,000 people, accounting for 5.2% of manufacturing employment (BIS, 2013). Furthermore, the UK is home to a number of niche engine manufacturers, reflecting a notable strength in the sector. However, a lack of a strong domestic supply chain and access to tier one suppliers represents a key challenge for the UK and its performance in the industry (Holweg et al, 2009; BIS, 2013).

The automotive industry is one of the most geographically fragmented sectors and has undergone a number of transformations in recent years (Türkcan & Ates, 2011). The trends and patterns characterising the production process of the automotive industry has been examined by a number of scholars applying a wide range of frameworks. For instance, the GVC framework has been employed to analyse the impact of the 2007-2008 financial crisis on the automotive value chain. Sturgeon & Van Biesebroeck (2010) noted that the financial crisis accelerated the growth and integration of developing nations into the industry, with the rise of emerging economy automakers through a number of significant acquisitions (such as China's Geely and India's Tata Motors). Furthermore, emerging economies are increasingly acting as important suppliers in the sector, with nations such as China and India further integrating into the automotive production network. China is increasingly acting as an important supplier of intermediate inputs to a number of leading automakers, including Japanese and Korean firms (Amighini, 2012).

A further area of study is whether production in this sector is regional or global. The automotive sector is often described as a "globalised industry", yet production is centred on a number of key regional production blocs (Schlie & Yip, 2000; Domański & Lung, 2009). Pavlínek & Žížalová (2014) note that trade in parts and components (rather than final goods) is heavily centred on regions, especially North America, Southeast Asia and Europe. Regional production clusters in the automotive industry do not only help facilitate production in geographical terms, but also serve markets with shared preferences, allowing the clusters to specialise in the customisation of vehicles to meet regional needs.

A number of features can influence the need for passenger vehicles to be customised to fit the needs of a certain market. Income levels of markets impact preferences; consumers from high income nations have higher expectations, such as more advanced and sophisticated features. Furthermore, vehicles must follow market standards and regulations, customising the production accordingly; these features are often shared at the regional level, such as European standards (Humphrey & Memedovic, 2003).

Overall, the automotive sector is an important sector in the global economy, both in terms of its contribution to employment and political significance. It is characterised by a production process taking place globally, yet certain activities are heavily centred around regional production blocs. In recent years a number of emerging economies, such as China and India, have become increasingly integrated into global production networks, often acting as key suppliers.

4. Data & Measures of Competitiveness

4.1. Data

Empirical fragmentation of production studies frequently utilise highly disaggregated bilateral trade data in order to map production patterns (Ng & Yeats, 1999; Yeats, 2001). This approach is followed in this study, making use of disaggregated trade statistics within the classifications of automotive components defined by Amighini & Gorgoni (2014), but supplementing these with final goods categories. By considering final goods trade networks, the behaviour of nations involved in the final stages of the automotive GVC is captured.

A network of final goods trade in the automotive sector was created based on the definition provided by Blázquez et al (2013), who make use of the gravity model to assess the effect of EU membership and specialisation levels on the integration of nations into the global automotive value chain. This definition was used by Blázquez & González-Díaz (2015) in an empirical network analysis of the automotive sector, examining a trade network of parts and components and a network of final goods. In a descriptive analysis of the networks for 1996 – 2009, they note consistent patterns between the structure of part and components and final goods networks. They identify regional tendencies, along with the networks becoming more integrated over time. In terms of specific nations, they note the rise of emerging economies taking key positions in the networks.

In this study, a boundary is applied to the network, only retaining trade ties which are at least 0.01% of world trade.[36] This is to ensure that only the most relevant ties (and countries) are included in the network, as weaker ties significantly increase network properties, such as reciprocity and density, yet contribute very little in terms of trade value. The networks are defined as a set of countries linked by trade, where the value of the ties indicate the proportion of world trade (therefore the tie value must be at least 0.01). The network data was collected at six time points for each component group (1994, 1998, 2002, 2006, 2010 and 2014).[37]

The data utilised in the construction of the ITNs and the calculation of the competitiveness measures was obtained from UN Comtrade (extracted using WITS) for a range of product codes within the industry, as listed in Appendix A. A range of country characteristics and measures of competitiveness at the product level were collated as described below.

Country characteristics are included: GDP, GDP per capita, regional partition, exchange rates, factor endowments and infrastructure. In this paper, a proxy is defined to capture

[36] The threshold was selected to ensure only the most relevant nations and ties were included in the network, yet that the majority of world trade (at least 90%) was retained. See Appendix A for percentage of world trade retained by applying this threshold.
[37] Descriptive statistics and visualisations of these networks are not provided here, rather these can be found in the works of Amighini & Gorgoni (2014) and Blázquez & González-Díaz (2015).

physical capital factor endowments, utilising a country's electrical power consumption/usage (Kwh per capita). This approach is utilised by Faustino & Leitão (2011) in their study on the determinants of vertical intra-industry trade in the automotive industry; testing whether vertical intra-industry trade occurs more frequently amongst nations with different factor endowment profiles.[38] When examining an industry characterised by a highly disintegrated production process, service links play an important role. Service links include communication and transportation infrastructure levels, which capture the extent to which nations can participate in production sharing (Blázquez et al, 2013). Therefore, internet users per one hundred people is utilised to capture infrastructure levels of a country. Service links can also be captured through GDP per capita, where more affluent nations tend to have improved linkages.

4.2. Measures of Competitiveness

Given the complexity and ambiguity of the competitiveness concept at the national level, a single measure cannot be relied on, rather a variety of indices are employed to capture the performance of nations participating in various stages of the automotive sector. In this paper, a combination of standard and relational measures of international competitiveness are used.

The standard measures available include a number of trade-based indices such as the RCA, RTA and variants of the normalised trade balance. Further measures are those provided by international organisations, such as the GCI and CIP metrics. In the context of the reorganisation of production, many of these indices become unsuitable, and lose much of their intuitive value. As noted by Baldone et al (2007), the fragmentation of production lessens the explanatory power of the RCA index. The RTA and other normalised balance measures experience a number of limitations in a sector characterised by a disintegrated production process, as they do not allow to capture the interplay between import performance (such as sourcing intermediate inputs) and the competitiveness of nations. For instance, the RTA is the revealed export advantage (RCA) minus the revealed import advantage (RMA), where the RMA is considered as measure of foreign competitiveness. Yet the RMA is often applied to reflect production sharing

[38] This proxy for physical capital endowments is applied in a number of studies, amongst them Zhang et al (2005) and Hoan Thanh Phan & Young Ji Jeong (2014).

patterns, where holding a RMA points towards a nation specialising in assembly operations (Kim, 2002).

The GCI is not necessarily appropriate in capturing the manufacturing performance of nations, especially in a complex supply chain; as the composite index only provides a broad measure, not necessarily suitable to capture the performance of nations in the automotive sector (Cinicioglu et al, 2012).

The composite metric utilised in this study is the CIP; this measure captures the manufacturing potential of nations, therefore provides a more suitable index to capture the competitiveness of nations in an industry characterised by a fragmented production chain. Furthermore, this measure provides an alternative to those based solely on international trade data.

Grodzicki (2014) suggests that global interdependencies have made standard indices based on international trade data (such as the RCA) less appropriate. These interdependencies suggest that a relational measure of competitiveness may be more suitable when examining a fragmented production process. Network analysis provides a number of alternatives in assessing the performance of nations; providing a relational approach to capture the various roles of countries in the ITN.

A number of network measures provide a suitable representation of the competitiveness of a nation in the ITN, in particular centrality measures. Centrality measures capture the extent to which an actor holds a prominent position in the network (Borgatti et al, 2013), so provide a natural indicator of performance. Weighted out-degree centrality provides a measure of export performance in the sector, Magerman et al (2013) use this as a measure of international competitiveness. Out-degree centrality is a count of the number of ties an actor sends in the network, whereas in-degree centrality is a count of the number of ties an actor receives (Freeman, 1978). In the context of the ITN, out-degree and in-degree centrality reflects the number of export and import ties of a nation respectively. Weighted out- (in-) degree centrality provides both a measure of the number of export (import) partners of a nation, as well as the contribution of these export (import) ties to total trade in the industry.[39]

[39] See Opsahl et al (2010) for the formulation of weighted out and in degree centrality measures employed in this paper.

A further index that can capture the performance of a nation is the hub score; this term has been discussed both in the network context and as an economic concept. In the economic context, the term hub is often used when describing the rise of China in the global economy, noting that it has emerged as a manufacturing "hub". Furthermore, Ferrarini (2013) notes that vertical trade is chiefly centred on a selection of hubs in the world economy: USA, Germany, Japan and China. The term hub has also been applied to capture the interdependence of a nation in the world or regional markets (Chen & De Lombaerde, 2014; Suder et al, 2015).

In network terms, an actor is considered a hub if it has a large number of outgoing ties pointed towards actors with high in-degree scores. In terms of the ITN, a hub refers to a nation that exports to central and important markets; where a hub can be thought of as a "factory of the world" (Deguchi et al, 2014).

A potential issue with using a network measure of competitiveness in a model that investigates whether performance is impacted by the position of a nation in a network is the potential correlation between network metrics, especially centrality measures. Centrality measures may be correlated, as they are all derived from the same adjacency matrix representing the network. However, Valente et al (2008: 6) demonstrate that although these measures are correlated to an extent, this varies vastly from case to case, reflecting that centrality measures are "distinct, yet conceptually related".

In this paper a number of measures of international competitiveness are employed; these each present a slightly different interpretation of competitiveness. These measures include hub scores, weighted out-degree centrality (export performance), and the CIP index.

5. Methodology & Model Specification

5.1. Temporal Network Autocorrelation Model (TNAM)

An advanced network model is used to address the research questions presented in section one: the Temporal Network Autocorrelation Model (TNAM). Autocorrelation models have been frequently applied in Social Network Analysis (SNA), chiefly to model social influence and contagion patterns, with Fujimoto et al (2011: 231) describing them as the "workhorse" for empirically testing for network effects on actor behaviour.

The autocorrelation model was first developed and applied to detect the presence of spatial autocorrelation, and its impact on a dependent variable (see Cliff & Ord, 1972).[40] In SNA, the autocorrelation model has primarily been applied to answer research questions concerning social influence, where the network captures the extent to which the behaviour of an alter impacts the behaviour of an ego (Leenders, 2002).

The model is applied by considering a weight matrix, W (the network), where w_{ij} reflects a tie between *i* and *j*, where the weight captures the extent to which actor *j* (the alter) influences the behaviour or performance of actor *i* (the ego). Leenders (2002) provides a detailed overview of the potential specifications of the weight matrix, chiefly in the social influence context.

The network autocorrelation model has been applied in a number of empirical settings, including academic performance (Vitale et al, 2016), the political sciences (Franzese & Hays, 2007; Franzese et al, 2012) and numerous social influence studies (amongst them Ibarra & Andrews, 1993; Fujimoto & Valente, 2012; Geng et al, 2015). Furthermore, the statistical power of the autocorrelation model has been examined by a number of scholars; specifically dealing with potential estimation bias issues (Mizruchi & Neuman, 2008; Neuman & Mizruchi, 2010; Wang et al, 2014).

A number of alternatives to autocorrelation models exist to model attributes based on network structure. For instance, Robins et al (2001) introduce a social influence model based on the Exponential Random Graph Model (ERGM) family of models; this was more recently extended by Daraganova & Robins (2013) as the Auto Logistic Actor Attribute Model (ALAAM). ALAAMs predict whether a node will possess a (binary) attribute based on the (binary) network structure. Within this model various local configurations are specified to investigate how patterns of ties may be associated with an attribute. Configurations include network positions, capturing the levels of activity in the network of nodes with the attribute, along with network attribute configurations, which capture the dependence between nodes with the attribute, such as contagion effects.

Tranmer et al (2014) present a Multiple Membership Multiple Classification Model, which shares a number of conceptual aspects with the network autocorrelation model, yet

[40] Variants of the network autocorrelation model have been developed in a number of subject areas, such as spatial econometrics, spatial statistics, along with SNA; although there is a level of overlap amongst these approaches, they have chiefly been developed in isolation (Hays et al, 2010).

chiefly deals with estimating the level of variation in the outcome variable. Tranmer et al (2016) apply this model to a multilevel network of emergency departments (sub-units) embedded in hospitals (organisations) and patient transfer ties amongst them, in order to assess the variation of emergency department waiting times (sub-unit performance).

The network autocorrelation model has experienced a number of improvements and extensions in recent years. Leifeld et al (2014) developed a longitudinal extension: the TNAM. The TNAM provides a generalisation of the ALAAM, potentially for multiple time steps and any kind of outcome distribution. The model allows the researcher to capture a number of structural effects and how these impact the dependent variable. For instance, the centrality of actors; this allows to test whether actors in the network occupying a more central position are more likely to have an increased dependent variable (such as performance).

The TNAM is one of the most comprehensive models available to investigate the performance of an actor in a network. The performance of an actor i is conditional on a wide range of variables, including actor covariates, the performance of other actors (at both current and previous time points), and the previous performance of actor i.

The model predicts the performance of an actor as a function of a number of dependencies, therefore the predicted performance of actor *i* may take the following form:

$$P\left(y_i^t \middle| A^{t-D,\dots,t}, X^{t-D,\dots,t}, Y^{t-D,\dots,t-1}, Y_{j\neq i}^t, \theta\right) = g^{-1}\left(\left[A^{t-D,\dots,t}, X^{t-D,\dots,t}, Y^{t-D,\dots,t-1}, Y_{j\neq i}^t\right]\beta\right)$$

Where:

- D is the temporal dependence with an upper bound of $D \epsilon \{0,1,\dots,T-1\}$
- $A^{t-D,\dots,t}$ which refers to current and/or recent networks
- $X^{t-D,\dots,t}$ which refers to current and/or recent covariates
- $Y^{t-D,\dots,t-1}$ which refers to current and/or recent actor performance (while $Y_{j\neq i}^t$)
- g^{-1} is the mean function appropriate to the edge distribution

5.2. Model Specification

The TNAM presents a highly flexible model to predict the attributes of actors embedded in a network, where a number of parameters can be specified. Table 19 outlines the parameters which can be included in the model along with their interpretation. The effects that can be specified in the TNAM include exogenous effects (as can be included in a standard regression model), attribute similarity effects and network effects, which can all be applied as predictors of performance.

Table 19 TNAM Effects

Term	Economic Interpretation
Covariate (Such as GDP, GDP per capita, exchange rate, infrastructure level)	This term captures whether a nation with a certain characteristic has a high performance level. For instance, are nations with a higher GDP more competitive?
Lagged Competitiveness Measure	This term captures whether the previous performance of a nation influences its current performance.
Netlag	This term captures whether the performance of a nation is affected by the performance of its trading partners.
Attribute Similarity	This term creates a similarity matrix based on an attribute. It captures whether two nations similar in one dimension (regional belonging) are more or less likely to be similar in another (competitive performance).
E-I Index	It captures the impact on performance of a nation having a regional or global trading profile. Where a negative (positive) and significant result would indicate that nations with regional (global) trading profiles are more likely to become competitive.
Brokerage Role by Regional Partition (Coordinator, Gatekeeper, Representative, Liaison, Consultant)	These terms capture whether holding a certain role within and between regional partitions increases the likelihood a nation will become competitive.
Out-degree Centrality	This captures whether nations with a high export level perform better.
In-degree Centrality	This captures whether nations with a high import level perform better.
Structural Similarity	The term captures the extent to which structurally similar nations in the ITN have similar performance levels.

A set of network effects are included in the model to address the first research question, to what extent is a country's economic performance in the automotive sector determined by its position in the ITN? More specifically, a set of centrality measures specified in the model to answer this research question. Where the in-degree and out-degree centrality capture whether a nation's import and export performance respectively, influences competitiveness levels.

An additional network effect is structural similarity, where a positive and significant effect would indicate that nations that hold structurally equivalent positions in the ITN are more likely to have similar performance levels.

The second research question presented by this paper asks to what extent is the economic performance of a nation in the automotive sector shaped by the performance of its trade partners? A netlag parameter is specified in the model in order to directly address the second research question. The netlag parameter captures how much direct trading partners influence the performance of nations in the automotive sector.[41] Where a positive and

[41] Within the modelling framework the terms weightlag and netlag are applied to capture the effect of the performance of direct partners for weighted and binary networks respectively. The terminology originates

significant parameter would indicate that if a nation trades with competitive nations, it is more likely to become competitive. The netlag parameter not only allows to test the impact of the performance of trade partners, it also provides the opportunity to operationalise and test the unequal exchange hypothesis proposed by Clark & Mahutga (2013). Where a negative and significant effect may indicate a mechanism of unequal exchange, where trading with less competitive nations increases the likelihood a nation will become competitive.

The third research question asked by this paper is to what extent does a nation's role at the regional level effect its economic performance in the automotive industry? In order to address the third research question, a set of regional level terms are included in the model specification; Kordalska & Olczyk (2014) note that export competitiveness is influenced by spatial effects, that the performance of neighbouring countries will affect export growth. The first is the regional similarity term (based on the attribute similarity effect); this allows to assess whether nations in the same region are more likely to share performance levels. Bahar et al (2014) argue nations in the same region share an "export basket"; therefore, the use of the regional similarity parameter provides the opportunity to test whether they also share performance levels. A positive and significant term would indicate shared performance, pointing towards nations acting as a complementary force to neighbouring countries. Whereas a negative and significant would indicate that there is an uneven distribution of performance within regional partitions.

Additionally, an effect to capture whether a nation with a regional or global trading profile is more likely to become competitive is included. This effect is the External – Internal (E-I) Index, a relational measure that assesses whether a nation's trade is mostly intra-regional or global. The index is based on the regional partitions, and assesses the number of trade ties a nation has inside and outside the partition (the external and internal ties).[42] The index gives a value between -1 and 1, where a negative value indicates a country has an intra-regional trading profile, whilst a positive value indicates a country has a global trading profile. When specified in the TNAM, a negative and significant effect would

from the spatial autoregressive modelling literature, where the term spatial lag is used to capture the effect of spatial autocorrelation (LeSage, 2008). For comparative purposes, the term netlag is used to refer to both the weighted and binary parameters.

[42] The E-I Index is defined as $\frac{E-I}{E+I}$ where is E is the number of external ties, and I is the number of internal ties (Krackhardt & Stern, 1988).

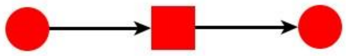
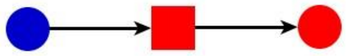
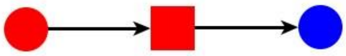
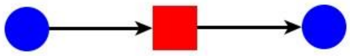
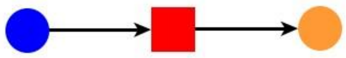
indicate that nations with a more regional trade profile are more likely to become competitive in the automotive industry. Although typically a network measure, it is possible to compute at the node level (Everett & Borgatti, 2012); in this paper it is computed at the country level.

Furthermore, a set of parameters to assess whether the role a nation plays within and between regions has an effect on its competitiveness levels are included, making use of the approach applied by Amighini & Gorgoni (2014). They use Gould & Fernandez's (1989) brokerage roles to distinguish the roles played by nations linking the various regional partitions. There are five brokerage roles (coordinator, gatekeeper, representative, consultant and liaison), indicating different positions a country may hold in the ITN. These five roles are included in the TNAM to test whether holding a certain brokerage role at the regional level increases the likelihood of a nation becoming competitive in the automotive industry. Table 20 presents a description of these five brokerage roles in the context of the ITN, along with a set of visualisations.

A nation is considered holding a coordinator role in an industry if it imports and exports to nations in the same regional grouping, coordinating trade at the regional level. The gatekeeper role captures the case when a country imports from a different region, then exports these goods to countries in its own region. For instance, it would capture the transit role of the Netherlands, where it imports large volumes globally to redistribute them across Europe. The representative role indicates where a nation imports from countries in its own region, then exports to countries in another regional partition.

Consultants act as external players, linking to a region (not their own), importing and exporting with this region. Liaisons link nations from different regions; indicating that the nation holds a stronger position in the global production network (over regional production sites).

Table 20 Description of Brokerage Roles

Brokerage Role	Visualisation	Description
Coordinator		Coordinators link countries in the same region, deepening region production sharing.
Gatekeeper		Gatekeepers import from other regions and then distribute exports in their own region, therefore acting as a regional supplier.
Representative		Representatives import from their own region and export outside the region. These nations act as global distributors for their region.
Consultant		Consultants link countries from the same region, where they act as external players to regional production networks.
Liaison		Countries acting as Liaisons link countries from different regional partitions.

Note: In the visualisation, the broker is indicated by a square, other nations by a circle. The different colours indicate regional partitions, where the same colour would indicate countries belong to the same regional partition.

The consultant and liaison roles have the weakest link to international trade in terms of their interpretation. They are included for consistency and to ensure full use of the complete set available, rather than using only a partial implementation of brokerage roles. Although it could be argued that the consultant role may reflect some form of offshoring or outsourcing tendencies; for instance, it potentially captures the case where a European nation exports to China for an assembly function, then China exports back to Europe, acting as a supplier. On the other hand, when utilised in the model, it is difficult to distinguish between this tendency (as there is not a focus on specific nations or regions) or whether it is simply inter-regional trade observed, such as the case where the US trades with Europe.[43]

A range of exogenous effects are included: GDP, GDP per capita, exchange rates, infrastructure levels and capital factor endowments. The GDP and GDP per capita terms allow to assess whether large and affluent nations are more likely to hold competitive positions in the automotive sector, and to control for size and income effects. Exchange

[43] The network metrics (such as brokerage role, E-I index) are calculated using UCINET (Borgatti et al, 2002) and the weighted out-degree centrality outcome variable is calculated using the tnet R package (Opsahl, 2009).

rates are included to control for cost competitiveness. When considering a fragmented production process, it is important to acknowledge that exchange rates may have a different impact, as various types of trade react differently to exchange rate movements (Cingolani et al, 2015).

Time lagged variables are used to capture the lagged influence of position in the production network on competitiveness, allowing further consideration of how holding an integrated position enhances performance over time. For instance, addressing whether an emerging economy that further integrates into the production network benefits from the change in its position in the ITN. The time points are every four years, rather than using the year-to-year changes, as a longer period of time allows to better capture the full effects of holding a certain position in a production network.[44]

The terms outlined in this section allow the assessment of the impact of previous relational effects and country covariates on current performance, where the TNAM is implemented as part of the xergm package in R (Leifeld et al, 2014).

5.3. Robustness Checks – Addressing Endogeneity

An issue that emerges from this modelling approach (and the specification of a number of network effects) to assess the competitiveness of nations is the endogeneity issue. As noted by Boehmke et al (2016: 124) this problem predominantly arises in network studies as a result of "using measures of one feature of the international system to explain another." Therefore, to alleviate the endogeneity issue in this study, the approach outlined by Boehmke et al (2016) is employed. More specifically, an Instrumental Variable (IV) two stage estimator approach is used.[45] The underlying concept associated with this technique is that endogeneity is stripped from the variables in question by substituting them with a set of suitable instruments. This paper follows the strategy outlined by Boehmke et al (2016), utilising a *Instrumented Network* in our estimation. In the two step estimator procedure, an instrumented network is utilised instead of a direct IV. This approach involves, firstly, simulating the ITN,[46] in order to create the Instrumented

[44] Furthermore, the use of lagged variables also helps deal with the problem of endogeneity, which concerns whether a network position (import performance, regional integration) improves competitiveness.
[45] Kali et al (2007) and Clark & Mahutga (2013) both make use of Instrumental Variable approaches during robustness checks to deal with potential endogeneity issues. It is also a technique frequently applied in the political sciences (Sovey & Green, 2011).
[46] Boehmke et al (2016) make use of the gravity model to simulate the ITN.

Network. This Instrumented Network is then used to construct the relational effects specified in the model, acting as IVs in the estimation process.

The first paper of this thesis highlights the importance of increasing interdependence as a feature of the world system, especially given the reorganisation of production. Therefore, when simulating the ITN to create the Instrumented Network, a Temporal Exponential Random Graph Model (TERGM), as developed by Hanneke et al (2010) is used.[47] This approach allows the simulation of a better set of instruments to be used in the estimation. However, the network simulated by the TERGM is a binary network. Therefore, the results of three estimations for each product group are presented (for each competitiveness index): Weighted Network, Binary Network and the Instrumented Network, where the final estimation acts as a robustness check. The use of both the weighted and binary model allows the examination of whether any substantial differences emerge when accounting for weighted ties; for instance, is it only the value (or volume) of trade that shapes competitiveness (as identified by the weighted network model), or is it also the underlying distribution of trade ties (as identified by the binary model)?

In the estimation process a time step must be dropped; when simulating the network, the TERGM estimation is conditioned on the covariates of the previous time point, where for the first observed ITN there are no previous covariates. Therefore, the estimation starts at t=1998, where the estimation is conditioned on the 1994 country covariates; as a result, simulated networks based on the TERGM are only available from 1998. For consistency across models, the TNAM is implemented from 1998 - 2014.

6. Results

6.1. Weighted Out Degree Centrality (Export Performance)

When considering the important players in the ITN, most descriptive studies make use of some variant of out-degree centrality (Amighini & Gorgoni, 2014; Reyes et al, 2014; Fagiolo et al, 2008). Where out-degree centrality captures the number of export ties a country has, the weighted out-degree measure goes a step further, accounting for the value of the ties, and assesses the contribution of the export ties of a nation to world trade. Therefore, it makes sense to make use of weighted out-degree centrality to measure the

[47] See the Appendix B for further details on the TERGM, and its use in simulating the Instrumented Network.

sectoral performance of a country. Table 21 presents the results of the TNAM using weighted out-degree centrality as a measure of export performance.

Across product groups and models, a number of parameters are consistently non-significant; these include the majority of country covariates, the E-I index and the structural similarity effect. On the other hand, previous performance has a consistent positive and significant effect across component categories. A parameter with mixed results across models is the impact of import performance (as indicated by in-degree centrality). The results suggest that high level of imports (in terms of trade value) have a negative and significant association with competitiveness. Yet the number of import partners does not have a significant effect, as indicated by the results of the binary model across product groups.

When considering the export performance of nations in the electrical automotive components production network, the results (for the most part) are consistent across the weighted and binary realisations of the networks and are robust (as indicated by the TNAM results for the instrumented network estimation). In terms of the covariates, there is only one notably result to mention, the negative and significant GDP per capita result. This highlights the rise of emerging economies in this slice of the automotive GVC and in the broader electronics supply chain (Sturgeon & Kawakami, 2010).

The role a nation holds within and between regional partitions significantly influences whether a country is a competitive exporter of electrical automotive components. Nations holding representative and consultant roles have a negative and significant association with competitiveness. Therefore, acting as an external player to a regional partition or as a global distributor does not increase the likelihood of becoming a competitive exporter.

The consultant result is not unexpected, given this component group is characterised by strong regionalisation patterns (as identified by Amighini & Gorgoni, 2014), acting as an external player to a region could be considered a redundant position.

A number of brokerage roles have a positive and significant association with competitive export performance; the coordinator and liaison roles. The coordinator role highlights that integration into the regional production network increases the likelihood of becoming a competitive exporter of electrical parts.

Table 21 TNAM Results for Weighted Out Degree Centrality

WO (Weighted Outdegree Centrality - Export Performance)	Electrical Weighted	Electrical Binary	Electrical IN	Engine Weighted	Engine Binary	Engine IN
(Intercept)	0.7601	0.7805	0.6861	-0.8372 **	-0.8592 **	-0.8589 **
	(0.5178)	(0.5363)	(0.5054)	(0.2795)	(0.2801)	(0.2849)
time	0.0005	0.0427	0.0480	-0.0162	-0.0111	-0.0139
	(0.0409)	(0.0419)	(0.0431)	(0.0350)	(0.0354)	(0.0349)
GDP	0.0485	0.0216	0.0215	0.0063	0.0007	0.0054
	(0.0296)	(0.0302)	(0.0275)	(0.0101)	(0.0103)	(0.0099)
GDP per capita	-0.1777 *	-0.1667 *	-0.1524 *	-0.0095	-0.0067	-0.0108
	(0.0698)	(0.0706)	(0.0659)	(0.0149)	(0.0150)	(0.0147)
Exchange Rates	-0.0117	-0.0055	-0.0067	0.0047	0.0078	0.0030
	(0.0220)	(0.0223)	(0.0207)	(0.0120)	(0.0120)	(0.0117)
Electric Consumption	-0.0086	0.0041	0.0105	-0.0086	-0.0092	-0.0179
	(0.0513)	(0.0528)	(0.0498)	(0.0287)	(0.0287)	(0.0282)
Internet Users	0.0273	-0.0046	-0.0024	0.0112	0.0030	0.0062
	(0.0306)	(0.0315)	(0.0308)	(0.0237)	(0.0238)	(0.0243)
E-I Index	0.0376	0.0247	0.0192	-0.0265	-0.0364	-0.0518
	(0.0699)	(0.0735)	(0.0775)	(0.0595)	(0.0593)	(0.0720)
Gatekeeper	0.0047	0.0040	0.0043	0.0096 **	0.0063	0.0143 ***
	(0.0031)	(0.0034)	(0.0039)	(0.0032)	(0.0035)	(0.0036)
Coordinator	0.0119 ***	0.0059	0.0086 **	-0.0000	-0.0059 *	-0.0108 ***
	(0.0028)	(0.0032)	(0.0031)	(0.0033)	(0.0026)	(0.0027)
Representative	-0.0112 ***	-0.0097 ***	-0.0156 ***	-0.0012	0.0019	0.0023
	(0.0024)	(0.0025)	(0.0024)	(0.0021)	(0.0020)	(0.0021)
Liaison	0.0109 ***	0.0122 ***	0.0062 ***	0.0131 ***	0.0098 **	0.0097 ***
	(0.0028)	(0.0029)	(0.0017)	(0.0038)	(0.0034)	(0.0023)
Consultant	-0.0168	-0.0591 ***	-0.0197 *	-0.0473 **	-0.0479 **	-0.0467 ***
	(0.0181)	(0.0163)	(0.0083)	(0.0169)	(0.0163)	(0.0098)
WO Lag 1	0.8051 ***	0.8401 ***	0.8911 ***	0.7930 ***	0.8649 ***	0.8982 ***
	(0.0387)	(0.0348)	(0.0289)	(0.0559)	(0.0263)	(0.0249)
Netlag	0.0137 ***	0.9226 *	1.0846 ***	0.0129 *	0.4620 *	0.5464 *
	(0.0041)	(0.3705)	(0.3172)	(0.0051)	(0.2232)	(0.2229)
Regional Similarity	-0.0138 **	-0.0106 *	-0.0111 *	-0.0019	-0.0005	-0.0005
	(0.0046)	(0.0049)	(0.0045)	(0.0018)	(0.0018)	(0.0018)
Indegree Centrality	-0.2307 ***	-0.0116	-0.0184	-0.0603 *	0.0058	-0.0014
	(0.0421)	(0.0159)	(0.0134)	(0.0266)	(0.0120)	(0.0116)
Structural Similarity	0.0013	0.0031	0.0002	0.0008	-0.0002	0.0005
	(0.0017)	(0.0038)	(0.0043)	(0.0013)	(0.0031)	(0.0035)
Log Likelihood	-581.8117	-594.7364	-583.0832	-360.4869	-356.7187	-352.8578
Num. groups: node	124	124	124	92	92	92

WO (Weighted Outdegree Centrality - Export Performance)	Miscellaneous Weighted	Miscellaneous Binary	Miscellaneous IN	Rubber & Metal Weighted	Rubber & Metal Binary	Rubber & Metal IN
(Intercept)	-0.1472	-0.1406	-0.0558	-0.0076	0.1863	0.2321
	(0.2671)	(0.2674)	(0.2634)	(0.2270)	(0.2320)	(0.2219)
time	-0.0082	0.0029	0.0069	-0.0130	0.0056	-0.0129
	(0.0280)	(0.0285)	(0.0290)	(0.0194)	(0.0190)	(0.0186)
GDP	-0.0137	-0.0275	-0.0293 *	0.0070	-0.0054	-0.0007
	(0.0136)	(0.0142)	(0.0136)	(0.0122)	(0.0123)	(0.0126)
GDP per capita	-0.0109	-0.0079	-0.0104	-0.0572 *	-0.0480	-0.0702 *
	(0.0169)	(0.0170)	(0.0172)	(0.0278)	(0.0277)	(0.0303)
Exchange Rates	-0.0313	-0.0119	-0.0065	-0.0165	-0.0113	-0.0074
	(0.0256)	(0.0254)	(0.0253)	(0.0103)	(0.0101)	(0.0107)
Electric Consumption	-0.0337	-0.0263	-0.0286	-0.0274	-0.0331	-0.0274
	(0.0290)	(0.0288)	(0.0289)	(0.0214)	(0.0212)	(0.0219)
Internet Users	0.0192	0.0120	0.0133	0.0301 *	0.0215	0.0396 *
	(0.0210)	(0.0212)	(0.0215)	(0.0141)	(0.0144)	(0.0158)
E-I Index	-0.0096	-0.0186	0.0211	0.0078	0.0162	0.0604
	(0.0559)	(0.0556)	(0.0650)	(0.0365)	(0.0370)	(0.0351)
Gatekeeper	0.0060 **	0.0059 *	0.0087 **	0.0060 *	0.0030	-0.0066 **
	(0.0022)	(0.0023)	(0.0027)	(0.0026)	(0.0026)	(0.0023)
Coordinator	-0.0004	-0.0051 *	-0.0075 ***	-0.0113	-0.0080	0.0305 ***
	(0.0024)	(0.0020)	(0.0020)	(0.0077)	(0.0078)	(0.0072)
Representative	0.0040 *	0.0061 ***	0.0023	-0.0008	-0.0033	-0.0003
	(0.0018)	(0.0016)	(0.0017)	(0.0027)	(0.0027)	(0.0017)
Liaison	0.0005	-0.0047 *	0.0048 *	-0.0003	-0.0029	0.0002
	(0.0025)	(0.0022)	(0.0021)	(0.0022)	(0.0021)	(0.0011)
Consultant	0.0132	0.0266 *	-0.0424 ***	0.0022	0.0082	0.0014
	(0.0118)	(0.0115)	(0.0093)	(0.0056)	(0.0055)	(0.0033)
WO Lag 1	0.7431 ***	0.8291 ***	0.9385 ***	0.9316 ***	0.9489 ***	0.9030 ***
	(0.0418)	(0.0277)	(0.0274)	(0.0456)	(0.0289)	(0.0155)
Netlag	0.0176 ***	0.5989 **	0.5616 **	0.0066	0.5271 ***	-0.1970
	(0.0042)	(0.1879)	(0.1898)	(0.0056)	(0.1462)	(0.1109)
Regional Similarity	-0.0002	0.0019	0.0016	0.0001	-0.0003	0.0006
	(0.0019)	(0.0020)	(0.0019)	(0.0017)	(0.0016)	(0.0017)
Indegree Centrality	-0.0979 **	-0.0088	-0.0054	-0.1266 ***	-0.0061	-0.0012
	(0.0330)	(0.0103)	(0.0101)	(0.0264)	(0.0058)	(0.0037)
Structural Similarity	0.0009	0.0017	0.0012	0.0001	-0.0010	-0.0013
	(0.0011)	(0.0030)	(0.0035)	(0.0008)	(0.0016)	(0.0008)
Log Likelihood	-312.0405	-310.7993	-316.0304	-289.6644	-292.259	-283.4825
Num. groups: node	105	105	105	147	147	147

WO (Weighted Outdegree Centrality - Export Performance)	Final Weighted	Final Binary	Final IN
(Intercept)	2.6368 ***	2.0011 ***	2.1034 ***
	(0.2447)	(0.2381)	(0.2381)
time	0.0295	-0.0208	0.0022
	(0.0194)	(0.0212)	(0.0210)
GDP	-0.1078 ***	-0.0738 ***	-0.0796 ***
	(0.0153)	(0.0141)	(0.0141)
GDP per capita	-0.0334	-0.0459	-0.0481
	(0.0354)	(0.0324)	(0.0339)
Exchange Rates	-0.0131	-0.0091	-0.0082
	(0.0115)	(0.0107)	(0.0109)
Electric Consumption	-0.0559 *	-0.0510 *	-0.0483 *
	(0.0244)	(0.0243)	(0.0245)
Internet Users	0.0276	0.0486 **	0.0432 *
	(0.0145)	(0.0163)	(0.0185)
E-I Index	0.0209	0.0176	0.0120
	(0.0366)	(0.0394)	(0.0345)
Gatekeeper	0.0020	0.0018	0.0029
	(0.0016)	(0.0018)	(0.0017)
Coordinator	0.0013	-0.0000	0.0037 **
	(0.0015)	(0.0015)	(0.0013)
Representative	0.0054 ***	0.0017	-0.0032 **
	(0.0011)	(0.0011)	(0.0012)
Liaison	0.0078 ***	0.0043 ***	-0.0021 *
	(0.0011)	(0.0011)	(0.0010)
Consultant	-0.0318 ***	-0.0187 **	0.0169 ***
	(0.0056)	(0.0060)	(0.0051)
WO Lag 1	0.4851 ***	0.8968 ***	0.9503 ***
	(0.0549)	(0.0229)	(0.0211)
Netlag	0.0664 ***	0.0217	-0.0438
	(0.0079)	(0.1594)	(0.1531)
Regional Similarity	-0.0012	-0.0012	-0.0009
	(0.0022)	(0.0019)	(0.0018)
Indegree Centrality	-0.0570 **	0.0037	0.0056
	(0.0197)	(0.0070)	(0.0066)
Structural Similarity	0.0003	-0.0004	-0.0030
	(0.0008)	(0.0016)	(0.0022)
Log Likelihood	-289.5935	-311.8568	-309.0341
Num. groups: node	140	140	140

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Note:

- *Weighted – Weighted ITN Model*
- *Binary – Binary ITN Model*
- *IN – Instrumented Network Model*

For electrical automotive components, the netlag parameter is also positive and significant; this indicates that developing efficient trade ties with other competitive nations increases the likelihood of becoming a competitive exporter.

The results of the TNAM highlight that the association between competitive export performance of engines and position in the ITN shares a number of features with the other component groups in the automotive sector, such as the import performance and previous competitive performance results. Similar to electrical parts, there is a positive and significant netlag result for engines, this suggests that developing efficient linkages to competitive exporters increases the likelihood of holding a competitive position.

The brokerage roles a nation holds within and between regions has a significant impact on engine export performance. The gatekeeper and liaison roles have a positive association, whereas the consultant and coordinator roles (yet only in the binary realisations of the ITN) have a negative association. This highlights the importance of acting as a regional supplier, rather than at the centre of the regional production network. The negative coordinator result is not unexpected in the engines production network, where Amighini & Gorgoni (2014) identify that the engines ITN does not have a clear regional structure, therefore holding an integrated role in a weakly structured regional production network is unlikely to enhance performance.

When assessing the export performance of nations in the miscellaneous components production network, the effect of import performance and past performance are consistent with the other product groups. However, the brokerage results differ from the other segments of the automotive GVC, and must be interpreted with caution; especially paying careful attention to the results from the instrumented network model. There is a positive and significant gatekeeper parameter across the three models, which suggests that acting as a regional supplier of miscellaneous components increases the likelihood of becoming a competitive exporter.

Furthermore, there is a negative coordinator role result, suggesting that integration into the regional production network is not associated with a competitive export performance; this perhaps reflects the decline in the levels of regionalisation in this product group over time (as identified by Amighini & Gorgoni, 2014).

The liaison and consultant roles are significant at the 5% level in the binary model, however, the sign switches in the instrumented network model (which acts as a robustness check). This indicates, whilst significant, these results are not necessarily robust. A possible explanation for this is that amongst the five brokerage roles, these two have the weakest interpretation in the context of international trade. The representative role shares some of these concerns; although positive and significant in the weighted and binary models, this significance falls away in the instrumented network model.

Although there are a number of features associated with a competitive export performance of rubber and metal parts that are shared with the other product groups (such as import patterns and previous performance), it exhibits a number of substantial differences.

Firstly, the role a nation plays at the regional level does not have a robust and significant association with a competitive export performance of rubber and metal parts. Secondly, the netlag result is not significant (although positive and significant for the binary realisation, it is not a robust result, as indicated by the instrumented network model). This suggests that developing efficient linkages in this low tech slice of the automotive value chain is not significantly associated with a competitive export performance.

The competitive export performance of the latter stage of the automotive GVC is characterised by a number of aspects are unique to the final goods category. The results indicate the role a nation holds within and between regions and the association with competitive performance must be interpreted with caution. Although there are a number of significant parameters across the weighted and binary network models, these results are not necessarily robust, as indicated by the instrumented network model. More specifically, these are the representative, liaison and consultant roles. The issues arising from the liaison and consultant roles are (again) potentially a result of the lack of explanatory power of these role in the context of the ITN.

The netlag parameter is only positive and significant in the weighted realisation of the ITN and non-significant elsewhere. This suggests in the case of final goods, only persistent trade with competitive nations will impact on the competitive export performance of countries.

6.2. Hub

The hub score indicates whether a nation is characterised as a factory of the world. The application of the TNAM in this case allows for an investigation of whether or not a country is a global producer of automotive parts. Table 22 indicates the results for the TNAM for the hub score, where across all models for each product group, past hub performance has a positive and significant effect on current performance levels.

A number of features have a significant association with whether a country is a factory of the world for electrical automotive components. The brokerage role results indicate that taking into account trade value levels impacts whether holding a certain role increases the likelihood of becoming a hub. For instance, acting as a regional supplier is positive and significant (at the 5% level), yet the significance disappears for the binary realisation of the production network. Furthermore, the liaison and consultant roles do not exhibit consistent results across models, highlighting the issues regarding the inclusion of brokerage roles which lack a strong interpretation in the ITN context.

The coordinator role is positive and significant, suggesting that integration at the regional level has a positive impact on performance (this also reflects the high levels of regionalisation observed in this component group).

In this product category, establishing efficient linkages with factories of the world is not significantly associated with hub levels (as indicated by the netlag parameter). The export performance results (out-degree centrality) indicate that it is not only the value of exports, but also the underlying binary distribution that determines whether a nation is more likely to become a factory of the world for electrical automotive components.

A number of features have a significant association with hub levels in the engine product group. The brokerage roles in this product group must be interpreted with care; whilst the gatekeeper and coordinator roles are significantly positive and negative respectively, this significance drops off in the instrumented network estimation.

Table 22 TNAM Results for Hub

HUB	Electrical Weighted	Electrical Binary	Electrical IN	Engine Weighted	Engine Binary	Engine IN	Miscellaneous Weighted	Miscellaneous Binary	Miscellaneous IN	Rubber & Metal Weighted	Rubber & Metal Binary	Rubber & Metal IN	Final Weighted	Final Binary	Final IN
(Intercept)	-0.0177	-0.0261	-0.0299	-0.0102	0.0021	-0.0120	-0.0172	-0.0166	-0.0199	-0.0261	-0.0107	-0.0115	0.0015	0.0021	0.0001
	(0.0170)	(0.0173)	(0.0178)	(0.0190)	(0.0199)	(0.0192)	(0.0156)	(0.0203)	(0.0189)	(0.0135)	(0.0137)	(0.0140)	(0.0077)	(0.0083)	(0.0080)
time	0.0009	0.0005	-0.0003	-0.0034	-0.0064	-0.0028	-0.0022	-0.0004	0.0010	-0.0023	-0.0029 *	-0.0032 *	-0.0020 *	-0.0019 *	-0.0014
	(0.0020)	(0.0020)	(0.0020)	(0.0035)	(0.0037)	(0.0038)	(0.0033)	(0.0039)	(0.0037)	(0.0014)	(0.0014)	(0.0015)	(0.0008)	(0.0008)	(0.0008)
GDP	0.0011	0.0008	0.0008	0.0000	0.0001	0.0002	0.0009	0.0009	0.0009	0.0018 **	0.0013	0.0023 **	-0.0003	-0.0003	-0.0004
	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0010)	(0.0009)	(0.0007)	(0.0007)	(0.0008)	(0.0004)	(0.0004)	(0.0004)
GDP per capita	-0.0033	-0.0024	-0.0024	0.0001	0.0000	-0.0001	-0.0006	-0.0004	-0.0005	-0.0036 *	-0.0030	-0.0052 **	-0.0004	-0.0004	0.0000
	(0.0020)	(0.0020)	(0.0020)	(0.0010)	(0.0011)	(0.0010)	(0.0011)	(0.0014)	(0.0013)	(0.0016)	(0.0016)	(0.0019)	(0.0009)	(0.0009)	(0.0009)
Exchange Rates	-0.0003	-0.0005	-0.0003	0.0005	0.0005	0.0001	-0.0002	-0.0005	-0.0002	-0.0007	-0.0005	-0.0004	0.0000	-0.0000	0.0002
	(0.0006)	(0.0006)	(0.0006)	(0.0008)	(0.0009)	(0.0008)	(0.0014)	(0.0020)	(0.0018)	(0.0006)	(0.0005)	(0.0006)	(0.0003)	(0.0003)	(0.0003)
Electric Consumption	0.0012	0.0009	0.0009	-0.0007	-0.0006	-0.0012	-0.0013	-0.0011	-0.0009	-0.0008	-0.0010	-0.0010	-0.0007	-0.0007	-0.0007
	(0.0018)	(0.0018)	(0.0018)	(0.0020)	(0.0021)	(0.0020)	(0.0017)	(0.0022)	(0.0020)	(0.0013)	(0.0012)	(0.0014)	(0.0007)	(0.0007)	(0.0007)
Internet Users	-0.0000	-0.0003	-0.0001	-0.0000	0.0013	0.0015	0.0002	0.0011	0.0006	0.0016	0.0017	0.0034 **	0.0007	0.0007	0.0003
	(0.0014)	(0.0014)	(0.0014)	(0.0016)	(0.0018)	(0.0016)	(0.0013)	(0.0017)	(0.0015)	(0.0010)	(0.0010)	(0.0011)	(0.0005)	(0.0006)	(0.0006)
E-I Index	0.0006	0.0001	0.0003	0.0010	0.0044	0.0052	0.0028	0.0082 *	0.0121 **	0.0001	0.0016	0.0054 *	0.0000	0.0000	0.0002
	(0.0028)	(0.0028)	(0.0035)	(0.0036)	(0.0039)	(0.0045)	(0.0027)	(0.0037)	(0.0042)	(0.0025)	(0.0025)	(0.0026)	(0.0011)	(0.0012)	(0.0011)
Gatekeeper	0.0003 *	0.0003	0.0002	0.0010 ***	0.0009 **	0.0003	0.0003 *	0.0002	0.0003	0.0001	-0.0001	-0.0007 ***	0.0002 **	0.0001 *	0.0002 ***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0003)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Coordinator	-0.0003 *	-0.0004 **	-0.0003 *	-0.0008 ***	-0.0005 *	-0.0001	-0.0003	-0.0003 *	-0.0008 ***	-0.0008	0.0009	0.0033 ***	0.0000	0.0000	0.0002 ***
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0006)	(0.0006)	(0.0005)	(0.0001)	(0.0000)	(0.0000)
Representative	-0.0000	0.0000	-0.0001	-0.0001	-0.0000	0.0002	-0.0001	0.0004 **	0.0006 ***	-0.0001	-0.0005 *	-0.0001	-0.0000	-0.0000	-0.0001 **
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Liaison	-0.0001	-0.0004 **	0.0002	-0.0004	-0.0002	-0.0012 ***	-0.0010 ***	-0.0007 ***	0.0006 ***	-0.0002	-0.0002	0.0001	0.0001	0.0001	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Consultant	0.0006	0.0017 *	-0.0013 **	-0.0015	-0.0020	0.0015 *	0.0036 ***	0.0032 **	-0.0052 ***	0.0003	0.0008 *	0.0001	-0.0007 **	-0.0004	0.0002
	(0.0009)	(0.0008)	(0.0004)	(0.0012)	(0.0012)	(0.0007)	(0.0008)	(0.0010)	(0.0007)	(0.0004)	(0.0004)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
HUB Lag 1	0.6157 ***	0.7873 ***	0.8370 ***	0.9065 ***	1.0977 ***	1.2176 ***	0.7938 ***	0.8608 ***	0.9793 ***	0.5737 ***	0.7724 ***	0.8505 ***	0.9339 ***	0.9439 ***	0.9643 ***
	(0.0467)	(0.0245)	(0.0241)	(0.0558)	(0.0493)	(0.0477)	(0.0387)	(0.0335)	(0.0364)	(0.0468)	(0.0223)	(0.0199)	(0.0195)	(0.0118)	(0.0116)
Netlag	-0.0049	-0.0148	0.0100	-0.0004	-0.0002	0.0103	0.0278 ***	0.0171	0.0110	0.0172 **	-0.0195	-0.0136	0.0413 ***	0.0032	0.0236 ***
	(0.0054)	(0.0144)	(0.0168)	(0.0046)	(0.0105)	(0.0112)	(0.0039)	(0.0105)	(0.0104)	(0.0065)	(0.0129)	(0.0103)	(0.0093)	(0.0067)	(0.0064)
Regional Similarity	-0.0050	0.0005	0.0033	0.0002	-0.0026	0.0060	-0.0032	-0.0082	-0.0097	0.0021	0.0000	0.0001	0.0009	0.0012	0.0010
	(0.0036)	(0.0039)	(0.0042)	(0.0055)	(0.0059)	(0.0064)	(0.0046)	(0.0055)	(0.0051)	(0.0031)	(0.0030)	(0.0034)	(0.0029)	(0.0032)	(0.0031)
Outdegree Centrlaity	0.0116 ***	0.0024 ***	0.0022 ***	0.0111 ***	0.0014	-0.0001	0.0147 ***	0.0005	0.0021 **	0.0239 ***	0.0022 ***	-0.0003	0.0003	0.0001	-0.0006 **
	(0.0022)	(0.0005)	(0.0006)	(0.0024)	(0.0008)	(0.0009)	(0.0025)	(0.0007)	(0.0008)	(0.0041)	(0.0003)	(0.0003)	(0.0012)	(0.0002)	(0.0002)
Indegree Centrality	-0.0023	-0.0010	-0.0009	0.0049 *	0.0002	0.0011	-0.0040 *	0.0000	-0.0008	-0.0061 ***	-0.0007 *	-0.0003	-0.0027 **	-0.0002	-0.0001
	(0.0018)	(0.0005)	(0.0005)	(0.0020)	(0.0009)	(0.0008)	(0.0017)	(0.0008)	(0.0007)	(0.0017)	(0.0003)	(0.0003)	(0.0008)	(0.0002)	(0.0002)
Structural Similarity	0.0005	-0.0012	-0.0028	-0.0052	-0.0112	-0.0422 **	-0.0004	-0.0064	-0.0094	-0.0002	-0.0031	-0.0039	0.0020	0.0004	0.0002
	(0.0041)	(0.0059)	(0.0074)	(0.0049)	(0.0096)	(0.0162)	(0.0031)	(0.0075)	(0.0074)	(0.0018)	(0.0029)	(0.0021)	(0.0018)	(0.0018)	(0.0028)
Log Likelihood	882.4247	884.1335	876.2701	582.3697	558.6814	583.9831	777.5556	700.1239	725.4517	1248.3292	1240.2302	1244.2525	1552.5902	1538.4025	1549.1817
Num. groups: node	124	124	124	92	92	92	105	105	105	147	147	147	140	140	140

****p < 0.001, **p < 0.01, *p < 0.05*

Note:

- *Weighted – Weighted ITN Model*
- *Binary – Binary ITN Model*
- *IN – Instrumented Network Model*

The out-degree result indicates exporting high volumes (yet not necessarily to a high number of markets) increases the likelihood of becoming a hub. This highlights the importance of serving a small selection of key markets to improve competitiveness levels in the production of engines. The in-degree centrality parameter is positive and significant (at the 5% level) for the weighted network estimation. This suggests having access to large volumes of intermediate inputs (yet not importing from a range of nations) increases the likelihood of becoming a global factory.

When examining whether a nation is a global producer of miscellaneous components, taking into account the value of exchanges amongst countries has a substantial impact on the modelling results. For instance, a number of parameters are significant when modelling the binary realisation of the network, yet are non-significant for the weighted case. These include the E-I index, representative and coordinator roles. The positive E-I index and negative coordinator results suggest that establishing global (binary) trading ties, (rather than regional), increases the likelihood of becoming a factory of the world in this segment of the value chain. The positive representative role suggests that acting as a global distributor (within binary production networks) has an association with acting as a global factory.

The gatekeeper role is only significant in the weighted network, suggesting acting as a regional supplier points towards an association with competitive producer performance (yet not in a substantially significant manner).

The liaison and consultant results exhibit issues regarding significance patterns across models, more specifically in the instrumented network model (the robustness check). Again, a potential explanation for the lack of consistency of these results in this product group, is that these roles lack a clear interpretation in the ITN setting.

The netlag parameter is positive and significant in the weighted model; this suggests that the strength of ties matter when examining how efficient linkages with competitive nations impact performance. In this case, establishing strong trading relations with factories of the world increases the likelihood of becoming a hub for miscellaneous components.

The out-degree centrality results highlight that the volume of exports, and to a lesser extent, the number of trade partners is positively associated with global producer performance. The in-degree centrality results are negative and significant, suggesting that assess to foreign intermediate inputs is not necessarily associated with becoming a factory of the world.

When examining what determines whether a nation is more likely to become a factory of the world for rubber and metal parts, there are a number of notable country covariates results that require comment. In particular, there is a tendency for larger emerging economies to be global producers in this slice of the automotive GVC; reflecting the rise of emerging economies in participating in low tech segments of the automotive supply chain.

In the case of rubber and metal parts, brokerage roles do not appear to have a significant association with hub performance levels. The netlag parameter is positive and significant, yet only for the weighted network. Therefore, in a similar manner to the miscellaneous components group, only developing strong efficient ties to factories of the world increases the likelihood of becoming a global producer of rubber and metal parts.

The centrality results point towards a positive and significant export performance and negative and significant import performance. However, this significance disappears in the instrumented network estimation.

In the case of the latter stages of the automotive GVC, the hub score reflects whether a nation is a global assembler of final automotive goods. The role a nation plays within and between regions influences whether it is a global assembler. For instance, there is a positive and significant gatekeeper effect, this suggests that distributing final automotive goods at the regional level is positively associated with a competitive performance.

The consultant role is negative and significant, yet only for the weighted network. However, this still highlights that acting as an external player to a region could be considered a redundant position in a sector characterised by regional trading patterns.

The netlag parameter is positive and significant, indicating that establishing efficient linkages to global assemblers increases the likelihood of becoming a factory of the world in the final stages of the automotive GVC. The import performance (as represented by in-degree centrality) is negative and significant, yet this significance drops off in the binary realisations of the ITNs. This result is not unexpected, given global assemblers are in a better position to serve the domestic market, so are less reliant on imports of additional final goods.

6.3. Competitive Industrial Performance (CIP)

The CIP provides a measure of manufacturing potential, derived from a number of indices in its formulation, including manufacturing value added. The use of this measure allows for assessment of the impact of a country's position in different stages of the automotive GVC on its industrial competitiveness. Furthermore, this index provides a measure of competitiveness that is external to the international system being modelled (the ITN), contrasting to the hub and weighted out-degree measures of performance. The results of this model are presented in Table 23.

There are a number of country covariates consistent across all models and groups; this is not unexpected given the CIP measure is external to the ITN, so the country covariates will influence the CIP in a similar manner across categories. There is a tendency for smaller, affluent countries with improved service links (as indicated by the internet users variable) to have a significant association with high CIP levels. Furthermore, there is a negative and significant factor endowments effect (as reflected by the electrical consumption variable). Previous CIP levels are consistently positive and significant across models and product categories. However, the effect of the position a nation holds within production networks varies across component groups.

The association between position in the ITN and CIP levels differ between the weighted and binary realisations of the network for electrical automotive components, especially in regards to the brokerage roles. For instance, in the weighted case, there is a positive and significant liaison role and negative and significant representative role. Whereas in the binary case, only the coordinator role is negative and significant. Although, the weighted and binary results are not entirely consistent, they both point towards an association between increased CIP level and holding a global position in the production network. This contrasts to the results of the weighted out-degree and hub measures, where an integrated position at the regional level has a positive impact on performance.

Table 23 TNAM Results for CIP

CIP	Electrical Weighted	Electrical Binary	Electrical IN	Engine Weighted	Engine Binary	Engine IN	Miscellaneous Weighted	Miscellaneous Binary	Miscellaneous IN	Rubber & Metal Weighted	Rubber & Metal Binary	Rubber & Metal IN	Final Weighted	Final Binary	Final IN
(Intercept)	0.2247 ***	0.2281 ***	0.2193 ***	0.1839 ***	0.2034 ***	0.2050 ***	0.1841 ***	0.1903 ***	0.2100 ***	0.2179 ***	0.2303 ***	0.2217 ***	0.2238 ***	0.2260 ***	0.2235 ***
	(0.0146)	(0.0139)	(0.0139)	(0.0189)	(0.0191)	(0.0187)	(0.0163)	(0.0157)	(0.0157)	(0.0214)	(0.0209)	(0.0212)	(0.0142)	(0.0142)	(0.0138)
time	-0.0006	-0.0005	-0.0019	-0.0001	-0.0006	-0.0013	-0.0004	0.0003	-0.0001	0.0004	0.0011	0.0009	0.0009	0.0006	0.0004
	(0.0010)	(0.0010)	(0.0011)	(0.0011)	(0.0012)	(0.0012)	(0.0010)	(0.0010)	(0.0011)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
GDP	-0.0125 ***	-0.0131 ***	-0.0124 ***	-0.0096 ***	-0.0103 ***	-0.0105 ***	-0.0101 ***	-0.0107 ***	-0.0115 ***	-0.0107 ***	-0.0110 ***	-0.0109 ***	-0.0096 ***	-0.0100 ***	-0.0095 ***
	(0.0011)	(0.0011)	(0.0011)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0007)	(0.0008)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
GDP per capita	0.0060 *	0.0058 *	0.0045	0.0019 ***	0.0020 ***	0.0021 ***	0.0022 ***	0.0024 ***	0.0024 ***	0.0056 **	0.0048 **	0.0029	0.0015	0.0014	-0.0001
	(0.0025)	(0.0024)	(0.0025)	(0.0004)	(0.0005)	(0.0005)	(0.0006)	(0.0006)	(0.0006)	(0.0018)	(0.0018)	(0.0019)	(0.0020)	(0.0021)	(0.0021)
Exchange Rates	0.0002	0.0001	-0.0005	0.0007	0.0008	0.0001	-0.0015	-0.0005	-0.0014	0.0001	0.0001	-0.0000	-0.0001	-0.0001	-0.0000
	(0.0006)	(0.0006)	(0.0006)	(0.0008)	(0.0008)	(0.0008)	(0.0010)	(0.0010)	(0.0011)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Electric Consumption	-0.0037 **	-0.0037 **	-0.0036 **	-0.0038 **	-0.0040 **	-0.0041 **	-0.0034 **	-0.0040 **	-0.0035 **	-0.0044 ***	-0.0057 ***	-0.0046 ***	-0.0046 ***	-0.0049 ***	-0.0044 ***
	(0.0012)	(0.0011)	(0.0011)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0010)	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0011)
Internet Users	0.0021 ***	0.0022 ***	0.0026 ***	0.0027 ***	0.0030 ***	0.0026 **	0.0025 ***	0.0021 **	0.0023 **	0.0019 ***	0.0018 **	0.0031 ***	0.0023 ***	0.0025 ***	0.0036 ***
	(0.0006)	(0.0006)	(0.0006)	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0007)	(0.0007)	(0.0005)	(0.0006)	(0.0007)	(0.0006)	(0.0006)	(0.0007)
E-I Index	0.0007	0.0003	-0.0011	0.0011	0.0011	0.0006	0.0016	0.0015	0.0015	0.0015	0.0017	-0.0017	0.0018	0.0021	0.0010
	(0.0015)	(0.0015)	(0.0015)	(0.0020)	(0.0020)	(0.0022)	(0.0022)	(0.0021)	(0.0023)	(0.0013)	(0.0013)	(0.0014)	(0.0015)	(0.0016)	(0.0013)
Gatekeeper	0.0001	0.0000	0.0003 ***	-0.0001	-0.0001	-0.0002	0.0000	0.0001	-0.0003 **	0.0001	0.0001	-0.0000	-0.0001	-0.0001	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Coordinator	0.0001	-0.0002 **	-0.0002 ***	0.0001	-0.0000	-0.0002 *	-0.0001	-0.0002 *	0.0001	-0.0005	-0.0002	0.0001	0.0000	0.0001	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0003)	(0.0003)	(0.0003)	(0.0001)	(0.0001)	(0.0001)
Representative	-0.0002 **	-0.0001	0.0000	-0.0001	-0.0000	0.0001	0.0003 ***	0.0004 ***	-0.0000	0.0000	-0.0001	0.0001	-0.0001 *	-0.0001 *	-0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Liaison	0.0002 **	0.0000	0.0001	0.0003 *	0.0002	-0.0001	-0.0000	-0.0001	0.0003 **	-0.0001	-0.0001	-0.0001	0.0000	0.0000	-0.0001
	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Consultant	-0.0006	0.0000	-0.0003	0.0000	-0.0001	0.0003	0.0003	0.0007	-0.0005	0.0004 *	0.0006 **	0.0000	0.0002	0.0003	0.0007 ***
	(0.0004)	(0.0003)	(0.0002)	(0.0005)	(0.0005)	(0.0002)	(0.0004)	(0.0004)	(0.0003)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0002)
CIP Lag 1	0.7707 ***	0.7588 ***	0.8236 ***	0.7823 ***	0.7740 ***	0.8138 ***	0.7775 ***	0.7627 ***	0.8557 ***	0.7115 ***	0.7884 ***	0.8549 ***	0.7264 ***	0.7889 ***	0.8316 ***
	(0.0348)	(0.0334)	(0.0282)	(0.0396)	(0.0406)	(0.0353)	(0.0401)	(0.0365)	(0.0344)	(0.0337)	(0.0301)	(0.0240)	(0.0374)	(0.0338)	(0.0294)
Netlag	-0.0045	0.0868 ***	0.0408	0.0235 **	0.0417	-0.0913 **	0.0273 **	0.1877 ***	0.0227	0.0271 ***	0.0820 ***	0.0239 **	0.0092	0.0743 **	0.0334
	(0.0061)	(0.0241)	(0.0227)	(0.0077)	(0.0414)	(0.0335)	(0.0103)	(0.0356)	(0.0346)	(0.0067)	(0.0186)	(0.0088)	(0.0056)	(0.0266)	(0.0279)
Regional Similarity	-0.0024	-0.0015	-0.0007	-0.0044 *	-0.0045 *	-0.0044 *	-0.0020	-0.0013	-0.0018	-0.0039	-0.0037	-0.0021	-0.0044 **	-0.0034 *	-0.0033 *
	(0.0015)	(0.0014)	(0.0014)	(0.0021)	(0.0021)	(0.0021)	(0.0017)	(0.0016)	(0.0017)	(0.0021)	(0.0020)	(0.0021)	(0.0014)	(0.0014)	(0.0013)
Outdegree Centrlaity	0.0049	0.0005	0.0001	-0.0046	-0.0001	0.0028 **	-0.0083 *	-0.0035 ***	-0.0001	-0.0044	-0.0005	-0.0003	0.0025	-0.0007	-0.0004
	(0.0028)	(0.0006)	(0.0005)	(0.0037)	(0.0009)	(0.0009)	(0.0038)	(0.0008)	(0.0009)	(0.0029)	(0.0003)	(0.0002)	(0.0033)	(0.0004)	(0.0006)
Indegree Centrality	0.0027 *	0.0006	0.0000	-0.0036 **	-0.0004	0.0004	-0.0006	0.0005	-0.0003	-0.0003	-0.0005	-0.0000	0.0013	-0.0003	-0.0004
	(0.0011)	(0.0004)	(0.0003)	(0.0013)	(0.0005)	(0.0004)	(0.0017)	(0.0004)	(0.0003)	(0.0020)	(0.0003)	(0.0002)	(0.0010)	(0.0003)	(0.0003)
Structural Similarity	0.0004 *	0.0003	0.0010 **	-0.0001	-0.0002	0.0008	0.0003	0.0002	0.0011	-0.0002	-0.0002	-0.0005	0.0002	0.0002	-0.0010 **
	(0.0002)	(0.0003)	(0.0003)	(0.0003)	(0.0005)	(0.0005)	(0.0003)	(0.0004)	(0.0006)	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0004)
Log Likelihood	1187.2538	1200.8351	1193.7104	810.907	800.4548	801.0614	967.6525	976.3959	961.7902	1461.6411	1456.3577	1434.3308	1362.7772	1355.144	1361.6585
Num. groups: node	124	124	124	92	92	92	105	105	105	147	147	147	140	140	140

****p < 0.001, **p < 0.01, *p < 0.05*

Note:

- *Weighted – Weighted ITN Model*
- *Binary – Binary ITN Model*
- *IN – Instrumented Network Model*

The netlag variable indicates mixed results, only significant for the binary network (yet not robustly so). Therefore, developing efficient electrical parts trade linkages to competitive nations does not significantly shape CIP levels.

The in-degree centrality results indicate that having access to large volumes of foreign intermediate inputs increase the likelihood of holding a competitive industrial performance; yet the number of import partners is not significantly associated with CIP levels. In this segment of the value chain, nations holding equivalent positions in the ITN are more likely to hold equivalent CIP levels. These results further highlight the differences between measuring performance using a composite metric and trade-based indices of competitiveness (as the tendency in the trade-based measures is for a negative in-degree parameter).

In the production of engines, the role a nation plays within and between regions does not have a significant association with CIP scores. Similar to the electrical parts group, the netlag parameter exhibits mixed results, highlighting the ambiguity between CIP levels and establishing efficient linkages to competitive nations in this segment of the automotive GVC.

Contrasting to electrical automotive parts, the in-degree centrality parameter is negative and significant for the weighted network (yet non-significant for the binary realisation). This suggests that in order to enhance manufacturing potential there is a need to develop the capabilities of domestic suppliers in this high tech slice of the automotive supply chain.

In the miscellaneous production network, the regional brokerage roles do not have a substantially significant association with the CIP of nations. The representative role is positive and significant, yet this significance disappears in the instrumental network estimation. The same pattern is also observed in the positive netlag and negative out-degree centrality parameters.

Unlike the other competitiveness measures or product groups, the consultant role is positive and significant in the CIP rubber and metal components category; however, this significance drops off in the robustness check (as indicated by the instrumented network results). The netlag term is positive and significant for rubber and metal parts; this indicates that developing efficient trade ties to nations with high industrial competitive levels has the potential to enhance the CIP.

In a similar manner to the other low tech categories in the automotive sector (miscellaneous components and rubber and metal parts), only a single brokerage role (representative) is significant for final goods, and this significance does not hold in the instrumented network estimation. The regional similarity parameter is negative and significant, indicating that within the final assembly production network, CIP levels are unevenly distributed within regions.

A potential explanation for the lack of significance of the relational effects in the miscellaneous components, rubber and metal parts and final assembly production network is due to the formulation of the CIP. The CIP is partly derived from the participation in high and medium tech industries, therefore, it is not a surprise that the position of a nation in segments of the automotive GVC with lower technological content lack a significant association with CIP levels.

7. Discussion of Results

The results from the TNAMs for the various measures of country performance highlight the clear differences between the competitiveness measures and their determinants, especially when comparing the aggregate CIP measure with the trade-based performance indices, where high levels of disparity are observed.

This paper outlined three key research questions in order to explain performance patterns of nations in the automotive sector, which were addressed through the use of a TNAM. The first research question asked to what extent is a country's performance in the automotive sector determined by its position in the international trade network? The answer to this question varies by both component groups and competitiveness measures. The use of the TNAM addressed this research question through the inclusion of a number of network effects in the model specification, such as the regional brokerage roles, in-degree centrality and structural similarity effects. The in-degree parameter provided a significant contribution in addressing this research question, as it allowed to test the impact of having access to intermediate inputs on economic performance in various slices of the automotive production chain. Where this allowed for an investigation into whether holding an importing position in the network significantly shaped performance.

The results across models and competitiveness measures point towards a negative impact of import performance (in terms of trade volumes). As shown in Tables 21 and 22, the effect of import performance has a significant impact on export performance (weighted out-degree centrality) and whether a nation is a factory of the world (hub performance) in the automotive sector. This suggests that in order to become a competitive player in various segments of the automotive GVC, there is a need to have access to domestic suppliers. Therefore, a potential policy implication could be to improve and develop the internal supply chain, and implement a set of polices to enhance the capabilities of domestic suppliers. Furthermore, access to intermediate inputs (either sourced domestically or internationally) allows for OEMs[48] and contract manufacturers to enter the local industry. In the UK, the nation is seen to hold notable advantages in the production of engines. However, in order to expand and develop in this segment, there is a need to overcome key weaknesses, specifically the state of the current internal supply chain and the availability of domestic suppliers (BIS, 2013). A higher number of domestic suppliers may also increase levels of integration of these contract manufacturers into the global supply chain, rather than becoming dependent on local plants (as often observed in engines production in the UK, as noted by Holweg et al, 2009). A shift to niches within a business function, such as a specific area of component production, allows a nation to increase value captured, acting as a key supplier to manufacturers operating in the broader component group.

The second research question presented by this paper asked whether the economic performance of a nation in the automotive sector was influenced by the performance of its trade partners? The specification of the netlag parameter provided an answer to this question across product groups for different measures of economic performance. The netlag results are consistently positive, and in most cases significant, indicating that establishing efficient trade relationships with competitive countries has a positive impact on national performance. This result is particularly evident for the weighted out-degree centrality and hub measures of competitiveness (see Tables 21 and 22 respectively). It also highlights that, in contrast to the findings of Clark & Mahutga (2013), there is not a process of unequal exchange occurring in the automotive ITNs.

[48]Original Equipment Manufacturers; which have become increasing integrated into the automotive production process over recent years (Dicken, 2003).

The third research question this paper asked was to what extent does a nations role at the regional level effect its economic performance in the automotive sector? This research question was addressed through the use of regional brokerage parameters and the E-I index specified in the TNAMs.

The regional brokerage roles provide some insights regarding the degree of power that a nation processes, despite not necessarily belonging to the core, and how this interacts with the notion of competitiveness. The regional brokerage roles are represented by the gatekeeper, coordinator, representative, liaison and consultant parameters specified in the TNAMs. The role a nation plays within and between regions has a significant effect on the likelihood of becoming competitive, yet varies across product groups and performance measures, as demonstrated by the contrasting results for these parameters observed in Tables 21, 22 and 23.

The brokerage roles a nation possesses has a significant effect on competitiveness in terms of export performance (out-degree centrality) and hub levels (see Tables 21 and 22 respectively), yet does not play a significant role in determining CIP levels (as demonstrated in Table 23). The results vary in terms of whether brokerage roles are significant and the sign of the effect. The consultant role should be interpreted with caution, as it could highlight the importance of intra-regional trade, where acting as an external player to a region may simply be a redundant role. The results highlight that acting as a gatekeeper has a positive association with competitive performance, (defined in terms of out-degree centrality or hub score), as demonstrated by the results presented in Tables 21 and 22. This emphasises that when investigating national competitiveness in a sector, there is need to take into account not only the role a nation plays within a region, but also how it links regional partitions.

Across the product groups and different measures of competitiveness, there appears to be a consistent negative (and in some cases significant) regional similarity effect. This indicates there is not a tendency for shared performance in regions, perhaps indicating the presence of a dominant player, suggesting a crowding-out effect at the regional level. On the other hand, given the high level of integration and intra-regional trade in the sector, this may indicate that nations source from others in the region, yet specialise in different functions to their neighbours in order to better exploit their comparative advantages (Bahar et al, 2014).

Furthermore, the rise of emerging economies in the production process has led to growing number of policy concerns. For instance, China's increasing integration in the electronics sector has led to many emerging markets (such as Latin American and East Asian nations) expressing concerns, often viewing China as a threat to export performance (Athukorala, 2009). Although electrical components are characterised as high tech products, not all nations trading these goods are involved in innovation-driven activities. China has become increasing integrated into the electronics value chain (Pham et al, 2016), yet it is not directly involved in high value adding functions, rather it acts as an assembly centre in the production network (Athukorala, 2009). This suggests that in the electrical automotive parts sector, high performing nations (based on trade measures of competitiveness) act as processing centres. The positive netlag parameter in the export performance model then highlights that trading with these centres that provide essential functions, allow nations to improve their own export performance and production capabilities. This suggests that in this sector, there may be a dominant player at the regional level (as indicated by the negative regional similarity parameter), yet does not necessarily indicate a process of crowding-out.

Along with the threat of emerging giants to developing nations, a number of additional competitiveness concerns have been expressed by nations in the world economy. In order for nations to formulate suitable policy, there is a need to better understand the structure of the global supply chain, and their position within various functions (Altenburg, 2007). In particular, the results highlight there is a need to be aware of the performance of trading partners; where in order to achieve an optimal position in the automotive supply chain there is a need to establish efficient linkages to competitive partners. This is especially important for nations with low development levels, in order to ensure they do not become trapped in low value, subordinate exchanges in the global economy.

With respect to the controls, a low level of significance was observed in the models, for instance, exchange rates did not significantly shape competitiveness levels (as observed in Tables 21, 22 and 23). Athukorala & Menon (2010) along with Avsar & Turkcan (2013) note that global production sharing tends to weaken the link between the effect of exchange rate movements on trade volumes, (and therefore trade competitiveness levels).

Physical capital factor endowment levels do not play a significant role in shaping the performance of nations in this sector (with the exception of the CIP case). One possible explanation is that fragmented production process has led to exports not only containing the factor endowments of the exporter, but also the endowments of the nations from which the country imports intermediate inputs (Beltramello et al, 2012).

Overall, when examining the competitiveness of nations in the production of automotive parts exports and their relationship to domestic value chains matter – not just the gross value, but also their distribution. Furthermore, when considering export performance of individual component groups, regional patterns and position play a significant role.

8. Concluding Comments

This paper aimed to address a number of research questions regarding the competitiveness of nations in order to present a step towards understanding the determinants of national performance in the automotive industry. It aimed to address whether a country's performance in the sector was determined by its position in ITNs and the performance of trading partners, along with its position at the regional level. This paper made use of a TNAM, applied to a range of ITNs at the more appropriate product level, to address these questions. The extent to which relational effects and the position of a nation in the trade networks vary by component groups, (which differ by technological content), and also vary depending on the measure of competitiveness employed.

The results from the TNAM indicate a number of patterns involving the performance of nations in the automotive sector. Firstly, they highlight that the way competitiveness is measured and defined matters, as various definitions suggest increased performance is determined by almost contradictory processes. For instance, the determinants of a nation as key player in the sector by weighted out-degree centrality clearly differs from what determines whether a nation has increased CIP levels.

A clear outcome of this study is that there is a need to better define competitiveness; one alternative proposed here is through the use of relational measures (such as the hub score). In light of the fragmentation of production, further research needs to be undertaken providing a descriptive comparison of the various competitiveness measures and country rankings. For instance, comparing the competitiveness ranks of nations based on their position in the ITN at the component level, with RCA of GVC incomes based on corresponding I-O data.

The TNAM results answer the first two research questions; the impact of position in the ITN and performance of trading partners on competitiveness varies depending on the measure of competitiveness. In terms of sectoral export performance (out-degree centrality) and whether a nation is a factory of the world (hub level), the position in the ITN and performance of trading partners has a significant effect. With respect to the CIP results, it is important to emphasise that when considering competitive patterns, the ITN structure should not be disregarded, rather for the CIP, only examining the trade networks of medium to high tech products is significantly associated with the CIP score. For low tech production, the CIP is less susceptible to structural influences; that the position of a nation in low tech ITNs does not significantly shape performance levels.

The third research question asks whether regional patterns shape performance in the automotive sector. In terms of the hub and export performance measures, brokerage roles have a significant effect, yet vary across product groups. This indicates that regional patterns matter in shaping the performance of nations in the automotive sector, yet the specific determinants at the regional level vary depending on how performance is captured.

Therefore, given the importance of regional effects, there is a need for policy makers to continue to create and sustain efficient linkages within regional production networks, in order to ensure that there is sufficient access to suppliers and intermediate inputs at the regional level. In the automotive sector, this refers to ensuring there is access to specialised inputs and services.

The modelling results, specifically the binary and instrumented network models, presents the opportunity to assess whether the conclusions still hold after the robustness checks. For the majority of cases, these results hold, where magnitudes and significance levels are relatively similar; however, certain results appear to exhibit robustness issues. These issues chiefly involved the brokerage roles, especially the liaison and consultant roles, which lack explanatory power in the ITN context. Even though the effects of regional position on performance seem plausible, endogeneity concerns cannot be entirely ruled out. Nevertheless, given the high level of models and measures applied, the majority of findings are consistent with the main results when examining the robustness checks presented by the instrumented network estimation. Nonetheless, these issues point towards a need to better understand the link between regionalisation activity and international competitiveness in a sector characterised by a fragmented production process.

In terms of measuring country competitiveness, relational indices provide a clearer measure of sector performance, as they are easily interpreted and allow for cross-country comparisons. Furthermore, unlike measures, such as the RTA, RCA and Lafay index, network measures of trade performance are not sensitive to small or non-existent export or import values; as the lack of ties would simply indicate a lower performance. Unlike the CIP, the relational measures also allow for a comparison between sectors of different technological content.

The results indicate that in order to increase a nations' position in a sector the product level or business function is more appropriate, as the determinants of national performance vastly differ amongst the products groups. The product categories vary in terms of technological content and value added to the economy. From a policy maker perspective, any attempts to upgrade to a higher value product group in the automotive GVC, should involve identifying their current position in the product group, along with the ideal position for the product (for example becoming a regional supplier of engines). Furthermore, policy makers should not disregard their position in lower value activities, rather there is a need to be aware of the position in these component groups, and specifically who acts as a supplier to them, and the performance of these suppliers.

In concluding, the main limitations of this study must be acknowledged. For instance, it is important to acknowledge when assessing country performance, it is at the firm level where the source of the competitiveness of nations lies. The performance of firms creates economic value and ultimately contributes to national competitiveness (Bhawsar & Chattopadhyay, 2015). Therefore, this suggests that a further avenue for future research would include developing and incorporating a measurement of competitiveness that links the micro firm level with the macro country level that is appropriate to be utilised in a study that takes the more appropriate task or business function perspective.

Overall, the TNAM provides a flexible approach to assess how both actor covariates and network effects impact the outcome variable, and demonstrate that network effects play a role in determining the competitiveness of a nations, along with the impact of the competitive levels of trading partners.

Appendix

Appendix A - Data & Network Threshold

Table 24 International Trade Product Codes (SITC Rev. 3)

Electrical Parts	
SITC Rev. 3 Code	Code Description
76211-76212	Radio-broadcast receivers not capable of operating without an external source
77812	Electric accumulators (storage batteries)
77823	Sealed-beam lamp units
Engines & Parts	
SITC Rev. 3 Code	Code Description
71321–71322	Reciprocating internal combustion piston engines for propelling vehicles
71323	Compression ignition internal combustion piston engines (diesel or semi-diesel)
77831	Electrical ignition or starting equipment of a kind used for spark ignition
77833	Parts of the equipment of heading 778.31
77834	Electrical lighting or signalling equipment
Miscellaneous Components	
SITC Rev. 3 Code	Code Description
7841	Chassis fitted with engines, for the motor vehicles of groups 722, 781
78421	Bodies (including cabs), for the motor vehicles of group 781
78425	Bodies (including cabs), for the motor vehicles of groups 722, 782
78431	Bumpers and parts thereof, of the motor vehicles of groups 722, 781, 782
78432	Other parts and accessories of bodies (including cabs)
78433	Brakes and servo brakes and parts thereof, of the motor vehicles of group
78434	Gearboxes of the motor vehicles of groups 722, 781, 782 and 783
78435	Drive-axles with differential, whether or not provided with other transmission
78436	Non-driving axles and parts thereof, of the motor vehicles of groups 722
78439	Other parts and accessories of the motor vehicles of groups 722, 781, 782
82112	Seats of a kind used for motor vehicles
Rubber & Metal Parts	
SITC Rev. 3 Code	Code Description
6251-62551	Tyres, pneumatic, new, of a kind used on motor cars (including station wagon)
62559	Tyres, pneumatic, new, other
62591	Inner tubes
62592	Retreaded tyres
62593	Used pneumatic tyres
62594	Solid or cushion tyres, interchangeable tyre treads and tyre flaps
69915	Other mountings, fittings and similar articles suitable for motor vehicle
69961	Anchors, grapnels and parts thereof, of iron or steel
Final Automotive Goods	
SITC Rev. 3 Code	Code Description
781	Motor cars and other motor vehicles principally designed for the transport of persons
782	Motor vehicles for the transport of goods and special-purpose motor vehicles
783	Other road motor vehicles
722	Tractors
74411	Self-propelled trucks powered by an electric motor, fitted with lifting or handling equipment

Table 25 Percentage of world trade retained by 0.01% threshold

Product Group	1994	1998	2002	2006	2010	2014
Electrical Components	92.76	92.22	91.30	91.89	91.14	94.00
Engines	95.50	95.73	95.44	94.87	94.19	95.15
Rubber & Metal Parts	92.89	92.42	91.86	91.78	91.66	93.16
Miscellaneous Components	95.07	94.8	94.79	94.08	93.7	94.75
Final Goods	95.48	95.41	95.31	94.53	93.94	95.05

Appendix B - Simulation of ITNs

The Temporal ERGM (TERGM) is utilised to construct the instrumented network to be used in the TNAM estimation. This firstly involved estimating the temporal model, then making use of the TERGM estimation to simulate the set of instrumented networks. Hanneke et al (2010) outline the specification of a TERGM for networks in discrete time, where at time t, the network has an ERGM distribution where the network statistics (or model parameters) specified in the model include both configurations of the network at time t, and configurations at previous time points, such as delayed reciprocity (Desmarais and Cranmer, 2012b). The configurations (or model parameters) specified in the model and their interpretation are outlined in Table 26. Table 27 presents the estimation results from the models used to simulate the ITNs

Table 26 TERGM Network Configurations

Effect	Economic Interpretation
Edges	This terms captures the baseline propensity for ties to be form in the network.
Activity Spread (GWODEGREE)	This term captures the extent to which (binary) export ties are evenly distributed in the network, or a concentrated in a handful of nations.
Popularity Spread (GWIDEGREE)	This term captures the extent to which (binary) import ties are evenly distributed in the network, or a concentrated in a handful of nations.
GWESP	This coefficient captures the tendency for triadic closure in the network, and therefore captures the tendency for hierarchical trading patterns in the network.
GWDSP	This term captures the extent to which nations are indirectly ties, trading with the same set of nations.
Mutual	This captures the extent to which trade ties between two nations are reciprocated.
Delayed Reciprocity	This captures the propensity for a one way trade relationship at t-1 to become a reciprocated trading tie at time t.
Stability (Memory)	This term captures the persistence of edges (and non-edges) from one time point to another.
Mutual (attribute)	This captures the extent to which there are reciprocated trade ties amongst nations with a certain attribute. For instance, Mutual Region would capture the extent to which trade ties are reciprocated within the same regional partition.
Nodematch	This captures the propensity for trade between two nations with the same characteristic. For instance, Nodematch Region would capture whether there is a tendency for intra-regional trade.
Nodeofactor/Nodeifactor	This captures the propensity for a nation with a certain attribute to export/ import.
Nodeocov/Nodeicov	This captures the propensity for a nation with a certain continuous characteristic to export – for instance, are larger nations more likely to export/import?
Absdiff (attribute)	This captures the propensity for a tie to form on the basis of the difference between the (continuous) attributes of two nations. For example, a positive and significant GDP parameter indicates nations of different sizes are more likely to trade.

Table 27 Estimation of the TERGM Results

	ELECTRICAL	ENGINES	MISCELLANEOUS	RUBBER & METAL	FINAL
Edges	-2.72 * [-3.02;-2.34]	-0.37 [-1.44;0.47]	-0.35 [-1.33;0.19]	-0.32 [-3.14;0.40]	-2.23 * [-2.59;-1.92]
Mutual	0.31 * [0.04;0.54]	0.67 * [0.16;0.97]	1.35 * [0.97; 1.72]	1.55 * [1.16; 1.74]	-0.1 [-0.26;0.09]
Popularity Spread	-1.34 [-2.05;0.27]	-2.58 * [-3.16;-1.95]	-1.58 * [-1.90;-1.17]	-1.17 * [-1.88;-0.95]	-0.06 [-0.21;0.31]
Activity Spread	-1.69 * [-2.01;-1.20]	-2.48 * [-2.68;-2.19]	-2.24 * [-2.95;-1.88]	-3.86 * [-4.25;-3.11]	-1.94 * [-2.33;-1.38]
GWESP	0.71 * [0.61;0.76]	0.37 * [0.19;0.54]	0.54 * [0.45;0.60]	1.06 * [0.91; 1.14]	0.73 * [0.70;0.78]
GWDSP	-0.04 * [-0.06;-0.01]	0 [-0.01;0.01]	0.01 [-0.01;0.02]	-0.11 * [-0.13;-0.08]	0.01 * [0.00;0.02]
Nodeofactor South Asia	0.1 [-0.43;0.66]	0.25 [-0.68; 1.14]	0.81 [-0.03; 1.43]	0 [-0.16;0.18]	0.81 * [0.51; 1.00]
Nodeofactor Middle East & North Africa	0.40 * [0.21;0.49]	0.11 [-0.30;0.54]	0.42 [-0.09;0.87]	0.13 * [0.02;0.23]	-0.11 [-1.01;0.54]
Nodeofactor Latin America & Caribbean	-0.23 [-0.54;0.02]	-0.44 [-1.10;0.16]	0.44 [-0.09;0.87]	0.01 [-0.54;0.28]	-0.28 [-0.89;0.10]
Nodeofactor North America	-0.74 [-1.60;0.09]	-2.54 * [-3.13;-2.05]	0.58 [-0.29; 1.26]	-2.26 * [-10.26;-1.47]	0.5 [-0.44; 1.19]
Nodeofactor East Asia & Pacific	0.99 * [0.57; 1.46]	0.29 [-0.21;0.82]	0.71 * [0.38; 1.01]	-0.13 [-0.22;0.09]	1.02 * [0.50; 1.46]
Nodeofactor Europe & Central Asia	0.07 [-0.17;0.36]	0.07 [-0.44;0.66]	0.71 * [0.20; 1.25]	-0.07 [-0.27;0.13]	-0.39 [-1.06;0.06]
Nodeifactor South Asia	-0.08 [-1.19;0.15]	-0.24 [-0.76;0.88]	-0.12 [-0.65; 1.21]	-1.54 * [-1.72;-1.25]	-0.15 [-0.70;0.34]
Nodeifactor Middle East & North Africa	-0.18 * [-0.81;-0.09]	-0.4 [-0.88;0.63]	-0.26 [-1.00;0.95]	-0.63 * [-0.85;-0.46]	0.26 * [0.11;0.45]
Nodeifactor Latin America & Caribbean	-0.28 * [-0.79;-0.15]	-0.26 [-0.75;0.81]	-0.07 [-0.56; 1.11]	-0.61 * [-0.77;-0.41]	-0.13 [-0.40;0.19]
Nodeifactor North America	-0.51 * [-1.06;-0.23]	-0.31 [-1.29;0.90]	0.09 [-0.44; 1.39]	-1.20 * [-1.53;-0.46]	0.4 [-0.41; 1.03]
Nodeifactor East Asia & Pacific	-0.99 * [-1.60;-0.75]	-0.88 [-1.34;0.19]	-0.35 [-1.22; 1.05]	-0.69 * [-1.08;-0.52]	-0.71 * [-1.30;-0.19]
Nodeifactor Europe & Central Asia	-0.48 * [-0.70;-0.32]	-0.71 [-1.21;0.27]	-0.26 [-0.97; 1.10]	-0.46 * [-0.68;-0.24]	-0.72 * [-0.99;-0.42]
Node Match Region	1.32 * [1.16; 1.54]	1.24 * [1.00; 1.50]	0.56 * [0.12; 1.08]	0.21 * [0.03;0.74]	1.30 * [1.06; 1.55]
Nodematch High Income Nation	0.06 [-0.10;0.15]	-0.09 [-0.31;0.06]	0.04 [-0.11;0.13]	-0.22 [-0.27;0.04]	0.17 [-0.05;0.34]
Nodeofactor High Income Nation	0.25 [-0.07;0.41]	-0.08 [-0.21;0.13]	-0.17 [-0.30;0.12]	-0.05 [-0.29;0.39]	0.19 [-0.03;0.50]
Nodeifactor High Income Nation	0.18 * [0.01;0.37]	-0.28 * [-0.41;-0.15]	-0.09 [-0.29;0.14]	-0.35 [-0.48;0.11]	-0.02 [-0.19;0.35]
Nodeocov GDP	1.25 * [1.01; 2.06]	1.34 * [0.90; 1.99]	0.21 * [0.00;0.44]	1.33 * [1.07; 1.59]	0.04 [-1.09;0.51]
Nodeicov GDP	1.00 * [0.72; 1.86]	1.00 * [0.59; 1.64]	0.14 [-0.12;0.36]	1.27 * [0.97; 1.51]	0.04 [-0.36;0.54]
Nodeocov GDP per capita	-0.56 * [-0.76;-0.42]	-0.03 [-0.35;0.20]	0.08 [-0.09;0.25]	-0.09 * [-0.20;-0.05]	0 [-0.00;0.00]
Nodeicov GDP per capita	0.02 [-0.13;0.13]	-0.09 [-0.36;0.25]	0.01 [-0.09;0.19]	0.41 * [0.34;0.45]	0 [-0.00;0.00]
Absdiff GDP	-0.82 * [-1.67;-0.53]	-0.75 * [-1.44;-0.24]	-0.18 [-0.40;0.03]	-0.91 * [-1.15;-0.63]	0.15 [-0.50;0.75]
Absdiff GDP per capita	-0.22 * [-0.34;-0.14]	-0.14 * [-0.38;-0.02]	0.05 [-0.13;0.16]	-0.26 * [-0.38;-0.11]	0 [-0.00;0.00]
Mutual Region	0.37 * [0.05;0.74]	0.41 * [0.02;0.87]	0.11 [-0.22;0.56]	-0.1 [-0.31;0.08]	0.84 * [0.50; 1.16]
Mutual High Income Nation	-0.02 [-0.33;0.28]	-0.02 [-0.28;0.24]	0.1 [-0.33;0.51]	0.05 [-0.11;0.22]	-0.38 * [-0.55;-0.25]
Delayed Reciprocity	0.42 * [0.13;0.75]	1.25 * [0.48; 3.26]	1.67 * [0.67; 4.81]	-2.51 [-2.68;0.12]	-1.33 * [-1.53;-0.26]
Memory/Stability	1.56 * [1.47; 1.69]	3.09 * [3.01; 3.30]	4.20 * [4.06; 4.38]	2.33 [-0.21; 3.20]	3.61 * [3.52; 3.82]

*Significant parameters are indicated by * where zero is outside the confidence interval*

Overall Conclusion

This thesis set out to examine the globalisation of industries from a relational perspective, more specifically, the disintegration of global supply chains in recent decades.

The three papers presented in this thesis provide an original contribution to knowledge; both individually and as a unified piece. The overall thesis points towards how a network methodology can aid in the explanation of production patterns given the transformation of the global economy, building on frameworks that advise a relational approach at the ontological level. The thesis presents ways in which various aspects of the global economy, such as international trade, investment and competitiveness patterns can be examined through a relational lens to overcome the analytical challenges presented by the globalisation of industries in past decades.

The first paper argues that network analysis can provide a contribution in explaining the transformation of the global economy. However, the paper emphasises that network analysis provides an alternative perspective to complement existing approaches and methodologies, not necessarily to replace them. Network analysis is a relatively recent and active field of study, where longitudinal and multilevel models are still experiencing high level of development. By contrast standardised methods are often more established in international business and economics. Therefore, in the first paper, the argument offered is that a relational approach provides the means to capture the increasingly interdependent nature of the global economy, building on the work developed through the application of conventional methods and approaches.

The second paper demonstrates the high level of dependencies amongst business group structure, investment choices and international trade. It argues that in order to better understand the locational choices of firms, their position in an ownership network or business group should not be ignored. It also applies a multilevel model to identify the trade and investment (and therefore production) patterns characterising a high tech industry. The multilevel perspective and analysis allows to overcome the fictitious separation of the micro (firm) level and macro (country) level when investigating issues related to the international organisation of production. The analysis presented in this paper identifies a number of trade and investment patterns present in the high tech medical and precision instruments sector. Amongst them is that this sector is characterised by hierarchical trading patterns, pointing towards a hierarchical division of labour. Intra-firm trade is not a significant feature of this industry and therefore suggests that investments are motivated by market-seeking and strategic-asset seeking tendencies.

The third paper presents a unique perspective in considering the performance of nations in the automotive sector, examining the interplay between competitiveness and the position of nations in a product level trade network. The analysis presented in this paper identifies a number of important findings. Firstly, that the product level is the more appropriate level of analysis when considering performance patterns in a sector with a disintegrated production process, as the determinants of performance vary substantially by component group. Secondly, there is a need for nations to develop the capabilities of domestic suppliers in order to enhance economic performance levels in the automotive industry. Thirdly, the performance levels of trading partners have a significant impact on competitiveness levels in the sector.

As a unified piece of work, this thesis fits into the broader research agenda explaining international trade, investment and therefore production in the modern global economy. It contributes to the existing programmes of work by international organisations, such as that of the UN Statistical Commission, which emphasises a need to develop and extend measurement frameworks to better explain international trade and economic globalisation (UNECE, 2015). The thesis adds to this programme of work as it provides a detailed overview of where empirical network analysis can better address research questions pertaining to the globalisation of industries in recent decades. It then provides two empirical examples for specific sectors, which demonstrates how network analysis can inform on two important topics; explaining the organisation of production utilising micro and macro data and the competitiveness of nations in global supply chains. This thesis demonstrates where a network methodology can aid in explaining features of the modern global economy, going beyond utilising the network term conceptually.

Although the thesis provides a key contribution in explaining the globalisation of industries in recent decades, in particular the fragmentation of production, it is not without its limitations. The two empirical papers represent two distinct advanced network modelling approaches, which are subject to a set of limitations. The second paper's key limit is that it is only able to model binary trade ties, relying only on an additional sensitivity analysis to identify the implications of using an alternative threshold. Furthermore, the multilevel model is restricted to the cross sectional case. In the third paper, a limit that emerges is the use of a small set of competitiveness measures, highlighting a need to better define the concept at the national level in light of the fragmentation of production.

The empirical work in the second and third papers demonstrate the value of network approaches to explain features of the global economy, however, these are limited to two sectors. Therefore, comments and conclusions made are limited to the medical and precision instruments and automotive sectors.

The research presented in this thesis presents how a network perspective can contribute in better explaining features of the global economy in light of globalisation. This thesis provides two examples of empirical work, therefore, there is scope to further extend the line of inquiry and the empirical research applying network analysis to explain international trade, investment and production patterns in the modern global economy.

The first paper highlights a number of advanced network models that could be used to examine international trade and investment to explain features of the global economy, some of which were not explored in this thesis. Amongst the models proposed were the recent developments in ERGMs to model spatial effects. This provides a clear avenue for further research, providing a framework to investigate where spatial features explain the network structure. In particular there is the opportunity to apply these to both international trade and investment networks at the industry level, allowing to explore the distance puzzle in a variety of settings.

The limitations of the work, such as the restriction to single sectors, suggest that there is a number of areas where the work in this thesis can be extended and explored in future studies. In particular, the novel dataset presented in the second paper offers a number of avenues for future research. Amongst them is the extension and development of relational multilevel datasets to a wider range of contexts and sectors. More specifically, identifying whether the interplay between trade, investment and business group structure differs by sector, especially in industries with varying levels of technological content. The development of a wider range of multilevel datasets provides a number of challenges; firstly, as sectors are heterogeneous, matching the product code at the macro level with the firms involved in production at the micro level may become increasingly difficult, especially for certain sectors. For instance, the creation of a dataset for the automotive sector would differ vastly from the case of the medical and precision industry; the medical devices sector is chiefly high tech, whereas automotive components can differ greatly in technological content (and therefore fragmentation levels).

A further development to this relational multilevel dataset would be to extend it to the longitudinal case. This would present a substantial data collection challenge, and additionally a model development challenge (as temporal multilevel ERGMs are currently unavailable). However, given the high level of interest in multilevel networks (Lazega & Snijders, 2016), and that network science is a relatively young and dynamic field; the development of longitudinal multilevel models is potentially an important objective for network scholars. The data collection challenge would involve having access to detailed firm level data in order to map the changes of both firm ownership ties, and the locational decisions of firms, and how these change over time.

The third paper examined the competitiveness of nations, where it highlighted the difficulties associated with appropriately measuring the competitiveness of nations in manufacturing industries. Therefore, what emerges as a possible avenue for future research is the development of competitiveness measures that are suitable for assessing a country's performance in a sector characterised by a disintegrated production process. Additionally, as the empirical study presented in the third paper is limited to the automotive sector, further efforts could be made to compare the results of the model to a different sector, in order to assess the interplay between the organisation of production and the factors that impact the competitiveness of nations.

This thesis presents two distinct advanced network models in order to analyse the fragmentation of production from a relational perspective; firstly, a multilevel model, and secondly a longitudinal network model. The multilevel approach was not extended into the third paper for a number of reasons; firstly, the availability of complete and fully operationalised multilevel models to analyse the effect of network structure on an outcome variable is limited. There is some scope in the application of multilevel ALAAMs, however, this approach is still very much in development. Furthermore, it is also subject to a number of limitations, specifically considering the complex concept of competitiveness as a binary variable, and is restricted to the cross sectional case. Whereas, the TNAM provided a more flexible approach to model the impact of network structure on competitiveness over time. Nevertheless, this emphasises a possible avenue for further research; to examine the competitiveness of nations from a multilevel network perspective, which would specifically acknowledge that it is firm level behaviour that ultimately determines a country's economic performance.

A further avenue for future research that stems from the findings of the third paper is a need to better understand the interplay between a country's position at the regional level and international competitiveness.

This thesis' aim was to contribute to the growing literature on the fragmentation of production from a relational perspective; noting the potential of utilising advanced network models to analyse features of the global economy. Subsequently the thesis demonstrated the value of advanced network models, providing an insight into how accounting for higher order network effects (in the case of the second paper, cross level effects), can improve our understanding of production patterns and national performance in the world today.

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