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Master Thesis

評估跨國人口移動與全球城市經濟互動之關聯性：

Multi-level ERGM 分析

Identifying the associations between cross-country human mobility and city-level economic interaction: Multi-level ERGM analysis

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Abstract

City economic interaction has long been a popular topic when it comes to global economic networks, especially when cities start to interact with each other individually. In past studies, scholars have been quantifying the economic interactions between cities through transportation data, such as airlines or railroads. However, the previous studies mostly constrained their study to one specific transportation method and they are not able to capture the idea of 'economic'. In addition, while cities play the one and only important role in the past study, the power of the country to the city is also neglected. To solve the two questions, cities and countries in the Americas and Europe have been chosen as the study area. The world city network (WCN) model is used to build economic network interactions between cities and the human business mobility data is used to represent the linkage between countries. Afterward, the multi-level exponential random graph model (ERGM) is applied to the model to interpret the power of countries on cities. The results show that comparing the model with only city-level, and the model with country-level added, the two model shows a completely different result, where the positions of countries have a greater impact on the city economic interaction and the morphologies in the model also shows the significant effect of

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the linkages between countries to cities. In other words, the power of counties over cities is significant. This study concludes that the positionality of countries and the network structure at the country level have a significant impact on the formation of economic interaction between cities.

Keywords: City network, country economic, business human mobility, WCN, world city network, ERGM

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摘要

近年來，在討論全球經濟網絡議題之時城市之間的經濟互動為不可忽視的重要因素。在過去的研究之中，諸多學者透過城市之間的旅運資料來量化城市之間的經濟互動，例如：飛航或是鐵路。然而，多數研究僅將研究專注在其中一種運輸模式之上，並且無法再研究資料之中捕捉「經濟」的面相。除此之外，由於城市在議題之中扮演重要角色，多數研究忽略了其國家在經濟網絡之中的影響力。回應以上兩個問題，本研究的研究樣區選定美洲以及歐洲的國家以及城市。全球經濟城市網絡（World city network, WCN）被用於建立城市之間的經濟互動，而國家之間的商業人口流動則是用於量化國家之間的連結。接著，多層指數隨機圖模型（Multi-level exponential random graph model, Multi-level ERGM）被用於解釋國家對城市經濟互動之間的影響。從模型結果可以看到，僅有城市層級的模型以及加入國家層級的兩個模型之間的結果顯著不同，顯示國家在網絡之中的位置對城市之間經濟互動的形成的影響為不可忽視的，同時，模型之中的各項結構也顯示國家層級之間的連結會影響城市層級之間的連結。本研究的研究結論為，國家層級間的各項網絡中心性以及網絡結構，皆對城市之間的經濟互動的形成有顯著影響。

關鍵字：城市網絡、國家經濟、人口商業移動、全球經濟網絡、多層指數隨機圖模型

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Content

doi:10.6342/NTU202203794

List of figures

doi:10.6342/NTU202203794

List of tables

doi:10.6342/NTU202203794

Chapter 1 Introduction

1.1 Background and Motivation

Under the trend of globalization, transportation systems, communications, and energy infrastructures are widely established and morphing our world system from divisions to connections (Khanna, 2016). The world has gradually evolved from vertical individual regions to a horizontal interdependent system, connectivity, therefore, plays an important part. The world is no longer viewed separately in regions, countries, or states, but is observed as an entire network system where countries or cities are seen as nodes and different forms of interactions between them are identified as edges.

Besides from observing the global network system on a country scale, cities have taken over the role while building the global network system. According to the statement in the UN's world city report in 2018, "by 2030, urban areas are projected to house 60 percent of people globally and one in every three people will live in cities with at least half a million inhabitants"(United Nations, 2018). As the economy develops over time, people are drawn to cites due to better individual wealth, convenient transportation and higher employment opportunity escalating

doi:10.6342/NTU202203794

the process of urbanization. Urbanization has cause industries to be spatially concentrated in megacities or urban regions. Cities started to specialize in specific industries, smaller cities focus on consumer service activities and huge metro areas such as New York and London are oriented to global financial and service (Henderson, 2010). Countries such as China and Japan have more than one city that has one of the largest populations in the world, super cities such as Tokyo even have a higher amount of population and GDP than some other countries. Without a doubt, instead of being seen as a part of a country, cities have developed individually and have their own history, culture, religion, and economics. Therefore, a body of studies have purposed to estimate cities in the global economic network in the pass few decades, and define the functionality and role of cities by their position in different kinds of network (Derudder & Taylor, 2021; Friedmann, 1995; Hennemann & Derudder, 2014; Sassen, 2013; Sigler & Martinus, 2017; Taylor, 2001).

When it comes to city economic network building, starting from analyzing the volume of international airline passengers (Derudder et al., 2008; Keeling, 1995), it is believed that transportation and communication infrastructures have a great impact on globalization and spatial organization. Due to the accessibility provided

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by transportation services, the flows of goods, people, information, and capital are created and enhance the regional economic development (Bowen, 2000). Moreover, transportation data are easy to obtain and is mainly about flows and good, which can be easily transformed into network data (Derudder & Witlox, 2005). Nevertheless, drawbacks still exist in the previous study, where most kinds of literature only focus on a certain kind of transportation system, such as airline, railroad (Derudder & Witlox, 2005), and yet it is difficult to capture the idea of ‘economic’ linkage by simply applying transportation data to the study since people travel for numerous of purposes (e.g. tourist) (Derudder et al., 2010).

Besides from human mobility, World City network quantifies the relations between cities using Advance Producer Service(APS) serving large global firms (Sassen, 1991; Taylor, 2001). Firms that provide global business services are defined as APS firms including law, accountancy, advertisement, management, etc. Based on the global location strategies, the connections between cities are based on the location of the APS firms’ offices and can be interpreted as intercity relations. Multinational firms are believed to generate the flow of knowledge and information between subsides (Ghoshal & Bartlett, 1990; Mayer et al., 2010; Sölvell & Birkinshaw, 2000), technologies and skills carried by the companies are

doi:10.6342/NTU202203794

also passed down to located cities, thus generating local economic development (Helg & Tajoli, 2004; Lin & Song, 2002). Therefore, the concept of the World City network is widely applied to the study of city economic network (Derudder et al., 2007; Pan et al., 2018; Sigler & Martinus, 2017; X. Zhao et al., 2020). After all, different social network analysis methodologies are applied to the created city network to observe the positionality of cities and the morphology between cities (Campante & Yanagizawa-Drott, 2018; Guo et al., 2020; Sigler & Martinus, 2017).

Even though the importance of the city is undeniable, studies have pointed out the inevitable dominating role of countries in cities (Agranoff & McGuire, 2003; Gereffi & Korzeniewicz, 1994). Gereffi and Korzeniewicz (1994) argues that: authorities and power relationships determine the flow of financial, material, and human resources. In other words, the allocation of goods or capital is dominated by national governments, whereas local regional economic development is dominated by intergovernmental competition (Schneider et al., 2003). There are insufficient data to document the power of countries to cities in the form of network. Cities are believed to exist with flows, connections, linkages, and relations within each other, but studies have purposed the idea that the higher-level national government is still dominating the local regional development (Shrestha,

doi:10.6342/NTU202203794

2010). Scholars nowadays estimate city networks in numerous kinds of datasets, either airline data or locations of multinational corporations, they are all constrained or under the control of national power, based on governmental relationships and agreements (Feiock et al., 2009; Olberding, 2002). However, works of literature mostly consider cities as a single actor in network analysis, country scale of relationship and network has not been taken into account in city network analysis.

To quantify country connections, cross-border mobility is often transformed into network data and estimated country relationships. Border-crossing mobility is even considered a new spatial pattern of economic and social life (Derudder et al., 2008), which can be used to estimate the interactions between countries or even cities with a smaller scale or more delicate dataset. People nowadays travel for numerous purposes, however, the global business environment has great contribution to the rising number of business traveling (Kulendran & Wilson, 2000). Recent researches have pointed out the indispensable of business traveling when it comes to estimating the global economy, where face-to-face interaction is still inevitable and required even in such an era of rapid development of technology (Aguilera, 2008; Beaverstock & Budd, 2013; Kulendran & Wilson,

doi:10.6342/NTU202203794

2000). This leads to a point that the business mobility between countries can be observed as the economic linkage and interactions between country-level government (Andersen & Dalgaard, 2011; Fagiolo & Santoni, 2015).

Although the idea of studying relations between cities at a global scale through human mobility or APS firms seems to be feasible, there are still some drawbacks to either one of the networks. The relationship between city interactions and the country connection is also unclear. Single layer of city networks are widely created and analyzed, where scholars focus on estimating the relationship between cities through pure city network and include other variables as nodal attributes (Akhavan et al., 2020; Chan et al., 2021; Sigler & Martinus, 2017). However, to have a comprehensive understanding of the global economic network, it is vital to include all the leading cities and dominant countries in the network.

1.2 Purpose

The objective of this study is to fill the gap of the lack of study in country-city relationships in the network aspect. Cities in the global economic network are assumed to be powered by their belonging countries, thus, country attributes such as GDP and population are expected to be related to city economic linkage. Based

doi:10.6342/NTU202203794

on the authorities and governmental power of countries to cities, morphology and positionality in country-level business travel network are expected to influence the formation of city economic interaction ties.

To achieve the goal, this study aims to, (i) Examine how country-level network affects the formation of city-level network, taking structural configurations and country-related attributes into account; (ii) Combine the concept of world city network and human mobility network focusing on business travel; (iii) Realize the morphology characteristic of city network form subnetworks.

doi:10.6342/NTU202203794

Chapter 2 Literature review

2.1 World City Network

When it comes to global economic networks, city interactions have taken over the leading role. Back in 1982, the World City hypothesis was advocated by Friedmann and Wolff (1982), in which they believed that instead of observing the global economy on a country scale, the scale should be minimized to a city scale. First of all, the function thesis states that a city could be the financial center of a country or region, which can lead the future developing directions or build up linkage with other regions through the city. Second, cities are believed to exist in a hierarchical relationship (hierarchical thesis), primary cities are cities where corporations organize production and plan market strategies, and they are more likely to have a higher degree of development (e.g. London). Secondary cities are the satellite of the o primary cities (e.g. Milan). and are linked to the primary cities. In *The Global City*, Sassen (1991) suggest that the more globalized the economy becomes, the higher the centralization is and forming the global cities. With the highly concentrated finance and producer service, global cities became the command points in regions and countries building urban hierarchies. In short,

doi:10.6342/NTU202203794

globalization has been generating a world system with a fundamentally new and different morphology (Alderson & Beckfield, 2004).

Based on the previous theory, Taylor (2001) proposed the concept of the World City network, which identified the economic interaction among global cities by involving multinational corporations. Since cities do not have decision-making administrations and competition between cities, the behavior of global corporate within and across cities are the ones that create the linkage in the city network. Deciding the offices' distribution is an expensive and important undertaking for corporations that provide business services in global scale. Derived from Sassen (1991) theory of the crucial role of APS firms in global cities, Taylor used APS firms to build up the World City network. The geographic locations of the offices have to fulfill the corporate goals, and the chosen city is believed to enhance intra-firm office network and intercity relations. Considering all the facts, the basic concept of the World City network is based on the relationship between global corporations' offices in different cities.

World City Network (WCN) research have been applied to different regions and industries. There are a handful of literatures that examine the formation and structure of the network like centrality, degree, or betweenness (Chong & Pan,

doi:10.6342/NTU202203794

2020; Derudder & Taylor, 2021; Hennemann & Derudder, 2014; Neal, 2011; Pan et al., 2018; Sigler & Martinus, 2017; X. Zhao et al., 2020). The above research has highlighted the essentials of social network analysis when it comes to exploring network structure and the position of cities. The ranking of cities examined with network structural descriptive statistics are proved to be incomparable from simply ranking by other city economic attributes (Krätke, 2014).

Sigler and Martinus (2017) have focused on the Australian Securities Exchange (ASX) listed firms (e.g. energy, materials, industrials, financials, etc.), social network analysis is afterward applied to the network. Their findings underline that rather than APS firms, with different centrality measures primary industries are not only highly international but highly influential in situating cities within global cities. With the industry base study, they have suggested that considerations are responsible for many of the spatial relations in different industries, such as the need for face-to-face depends on the working environment in different cities. Akhavan et al. (2020) extended the study to econometric analysis and ordinary least square regression to estimate the determinants of the network with the third-party logistics firms, which provide both material/operational activities and high-

doi:10.6342/NTU202203794

value informational services. By applying the ordinary least square model, besides network analysis, other city attributes such as low-skilled labor and traffic are proved to affect city ranking. The study also states that even though the city is ranked the first physical freight city, it does not correspond to being the control point in the network. Chong and Pan (2020) explored the WCN by applying Exponential Random Graph Model regression and took in city-related attributes such as GDP, transportation, wage, or populations. The study proposed that attributes are influential factors affecting the network structure.

In conclusion, WCN is not only limited to APS firms but also can be applied to other industry especially considering the requirement of face-to-face interaction. Network configuration can be examined in multiple different methodologies as well as the city positions are crucial factors while exploring the network structure and formation.

2.2 The power of countries to cities in economy

Regional economic is seen as a primary local responsibility with the assistance and permission form states and federal (Gordon, 2007), however, the collaboration between local governments may cause conflicts due to an imbalance power and

doi:10.6342/NTU202203794

unreliable cooperation (Visser, 2002). Unlike regional collaboration, national-level governmental collaboration provides reputational relations and generates mutual reliance (Gereffi, 2018). The partnership and competition between national government both dominate local regional developments, while partnership creates a desirable environment for regional government connection (Feiock et al., 2009; Olberding, 2002), and competition relations between countries may monopolize regional economic development.

In the study of Smith et al. (2019) that applied the world city network to estimate the network between international organizations has suggested that the ownership (nationality of organizations) is proven to be essential while estimating international trade between corporations. Results of the studies have also suggested that country-level configurations have significantly influenced the formation of the inter-firm network. In this case, the same theory could be applied to the city economic network since the multinational firm dataset can also be transformed into a city network (Taylor, 2011), and the crucial of ownership has been proved to affect the network structures. On the other hand, collaborative policy network and inter-organizational network has been built to estimate the mechanism of economic development, with a finding of government playing the

doi:10.6342/NTU202203794

role of constraints and opportunities that creates economic development (I. W. Lee et al., 2012). This study tried to combine the governmental belonging network and relationship network into one, however, the two networks merely merge into one, instead of realizing the hierarchical relationship between government and organizations, all the nodes are set to the same level but with different attributes. Yet, without setting the networks in a hierarchical structure, even with the application of ERGM, it is not possible to realize the positionality and relationship between different types of nodes.

2.3 Human mobility and economy

In this generation, most people rely on the convenience of the internet for communicating through phone or skype and other software, which provide quick access for people to get in touch instantly and reduce the cost of communication. However, pieces of evidence have shown that the amount of traveling has rapidly increased in the past few decades (Salas, 2022). Transportation infrastructures such as roadway, railway, air transportation, and water transportation are wieldy created and considered with high contribution to economic performance in higher payoff, attracting investment, or labor quality (Hong et al., 2011).

doi:10.6342/NTU202203794

Human mobility may create various spillover effects on its surrounding environment. Evidence has shown that the expansion in road mobility enhances economic growth, and enable the transportation of goods and services across regions (Ng et al., 2017). Conventional transportation system such as high-speed rail (HSR) creates a linkage between cities and represents the urban hierarchical structures, providing accessibility and representing economic development in the spatial aspect (Guo et al., 2020; Jiao et al., 2017). A body of literature has pointed out the great impact of cross-country mobility via airline travel on economic development. In the study of the United States, cross-border business travel has also been found to raise a country's rate of innovation (Coscia et al., 2020). Campante and Yanagizawa-Drott (2018) attempted to emphasize the impact of long-distance direct flights on the economic development at the local level by examining the distance between the airport and the office of corporations, and stats that airline connections increase business links and flows.

Scholars have proven the importance of meeting face-to-face in business activities (Brueckner, 2003; Derudder et al., 2008; Storper & Venables, 2004). Coscia et al. (2020) claims that even under the increasing availability of new communication technologies, business travel has not just endured, but even expanded. Face-to-

doi:10.6342/NTU202203794

face interaction is still preferred in tacit knowledge exchange, which refers to competence and skills (know-how) and information about who knows what and who knows how to do what (know-who) (Aguilera, 2008). A study illustrated by Lissoni (2001) has purposed that tacit knowledge is indispensable to identify and forage alliances with customers and suppliers. In this case, business travel enables face-to-face contact through tacit knowledge, and diffuse trust while social networks can develop at the same time. However, people travel for numerous purposes (e.g. tourism, visiting), and it is difficult to distinguish trips associated with business activities. Simply using the airline, railroad, or water transportation data could not focus on business travel, data will inevitably contain irrelevant mobility data.

Kulendran and Wilson (2000) examined the determinants of business trips to Australia from the United States, the United Kingdom, Japan, and New Zealand back in 2000, with the finding openness to trade and origin country income are important variables explaining business travels to Australia. On the other side, business traveling also has a certain impact to exchange rates, business confidence can influence demands for foreign currency through outgoing business tourist expenditures.

doi:10.6342/NTU202203794

Chapter 3 Data and methods

3.1 Study area

This study area of this research focuses on North America, South America, and Europe (excluding Russia), which includes 82 countries in total, with almost two billion of population located (Figure 1). A majority of the top multinational corporations are located in America and Europe. Moreover, the human mobility network is a locational based data released by Facebook in 2020, however, from the population ratio distribution of Facebook users, there is barely any users located in China and Russia (Figure 2), while a large number of companies

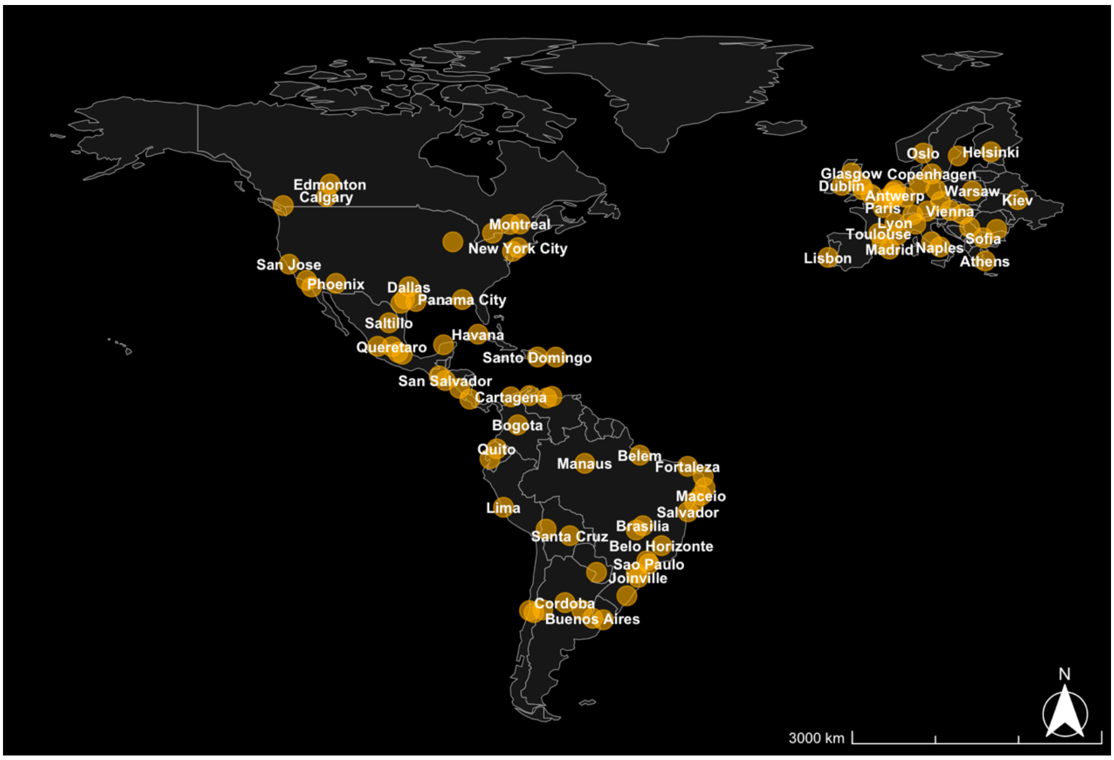

Figure 1 Study area: North America, South America, Europe (exclude Russia)

doi:10.6342/NTU202203794

branches are located in China and with a high density of linkage with other Asia cities. Including the entire world will cause a serious underestimation result, therefore, the Americas and Europe are the selected study area of this study. Therefore, Figure 1 distributes the 103 cities that are selected in the study area and included in the study.

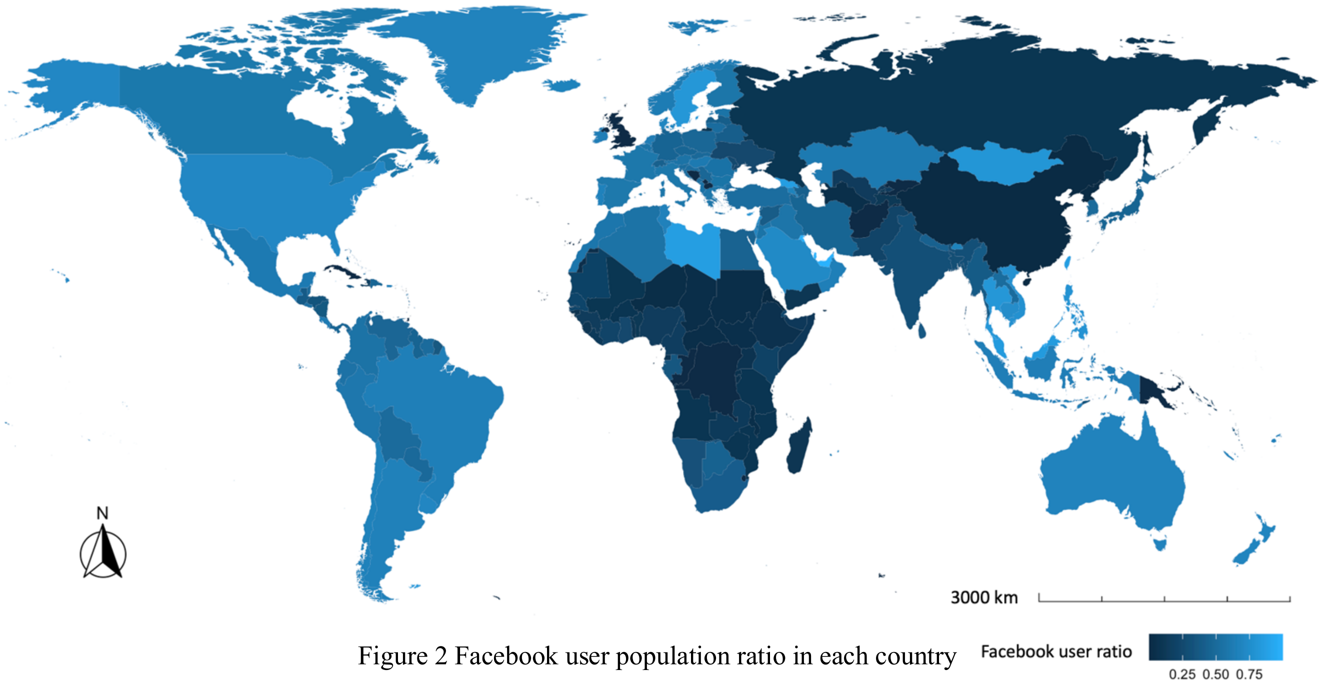

Figure 2 Facebook user population ratio in each country

3.2 Data

The data in this study includes two types of data: City economic network, and business travel data with the GDP and population data (Lin & Song, 2002) as nodal attributes in country scale.

doi:10.6342/NTU202203794

City economic network

Following the demonstration of the World City network with APS firms by Taylor (2001), the Orbis database developed by Bureau Van Dijk is used as the main data source for the construction of interlocking network between firms. The Orbis database ranked the top 500 corporations by their annual revenue in 2021, consist all the existed companies without industry selection. Based on the definition of the industry from Bureau Van Dijk, the type of corporation across 17 types of industries (e.g. banking, business service, electric, retail, etc.). Among the top 500 companies involved, headquarters are located in 44 countries worldwide, and the majority location of headquarters are distributed in United States and China (Figure 3). Regarding the branches, after aggregating the 262,994 branches of the 500 firms located in the same city, 115 countries and 18,518 cities are found to be distributed. Besides from the edges, the number of branches located in per city is set as an nodal attribute of city, the higher the number is, the more important the city is to the 500 companies.

doi:10.6342/NTU202203794

Business travel network

The wide spread of COVID-19 has triggered many governments in different countries to implement travel restrictions to reduce the volume of cross-border mobility since 2019, international mobility has greatly declined since the outbreak of COVID-19. Instead of the restriction policy, studies have claimed that the decline in mobility is mostly driven by the fear of infection (Goolsbee & Syverson, 2021). By observing the daily cross-border mobility data during COVID-19, Docquier et al. (2022) shows that among all the selected features, variable total changes in traffic have the lowest correlation with epidemiological intensity during COVID-19, which suggests that the fear of getting infected has less impact on cross-border mobility. On the other hand, besides variables such as school closure and cancellation of events, international travels have the least effect on

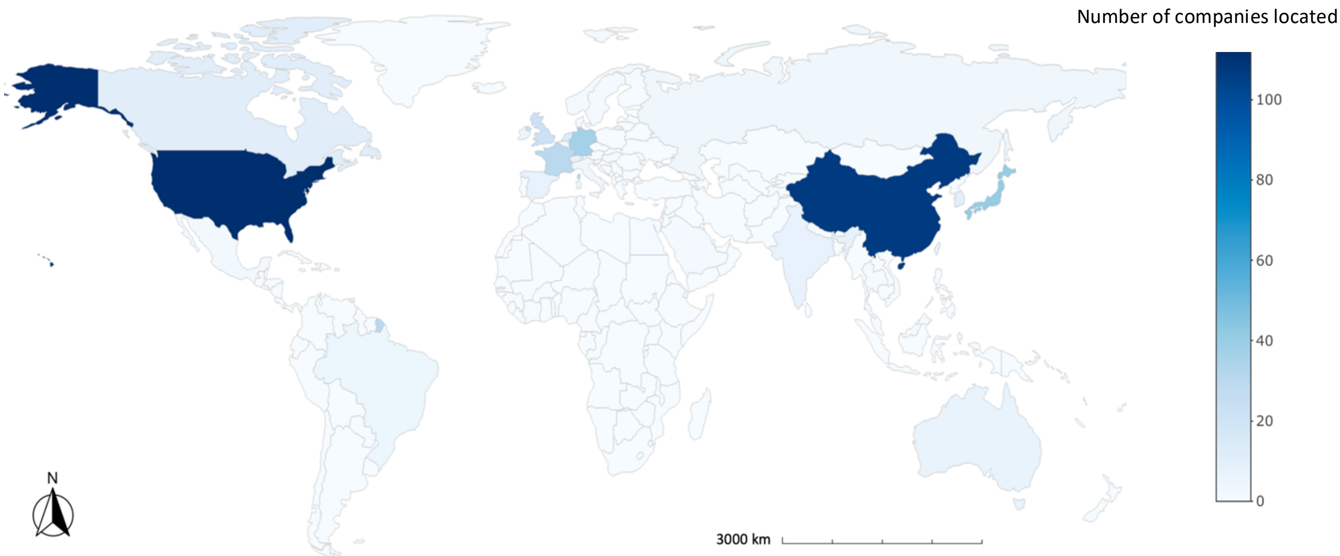

Figure 3 Orbis top 500 companies headquarter location

doi:10.6342/NTU202203794

cross-border mobility. Therefore, the study suggested that travel restrictions and the fear of infection only affects non-essential travels, human mobility during the pandemic are mostly based on business travels. Economic travels involve labor communication flows and essential business travels, which they hardly adapt to epidemiological threats that can only be limited by strict restrictions.

The human mobility data is obtained from Facebook (Meta, 2021) in the period of January to December of 2020 (Figure *5*). The database focus on the location, movements, mobility of active FB users, and provides their cross-border flows. The locations of the users are collected at daily based, and whoever travels from

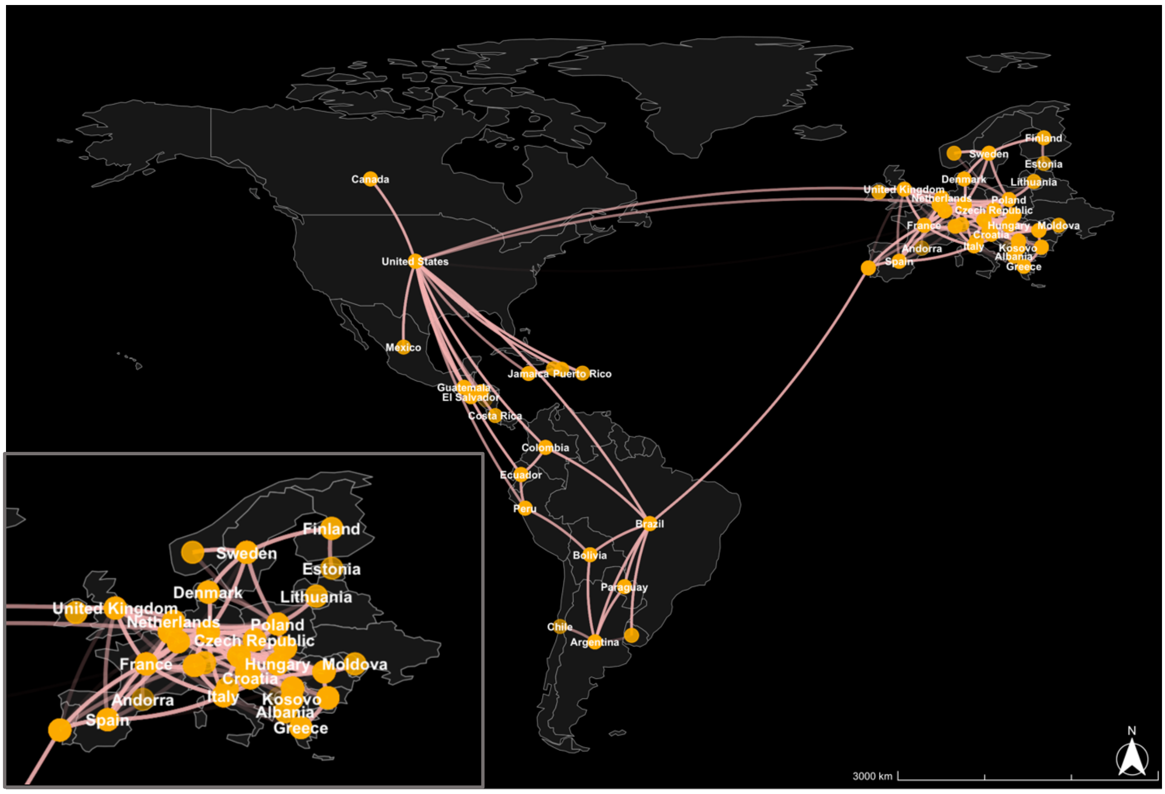

Figure 4 2020 Facebook human mobility map

doi:10.6342/NTU202203794

one country to another by all means of transportation methods (e.g. car, railroad, airline) are included. The database involves 121 countries worldwide, each pair of country has their own mobility flow (Figure *4*).

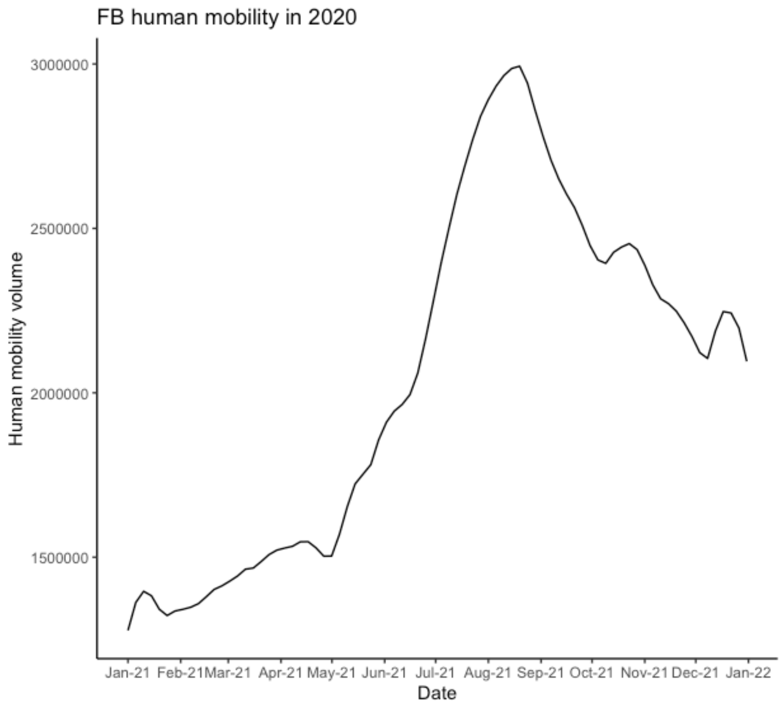

Figure 5 Facebook 2020 human daily basis mobility data

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3.3 Research frame work

The research frame work is shown in Figure 6 with the data processing part circled in yellow and two analysis methods displayed in the bottom.

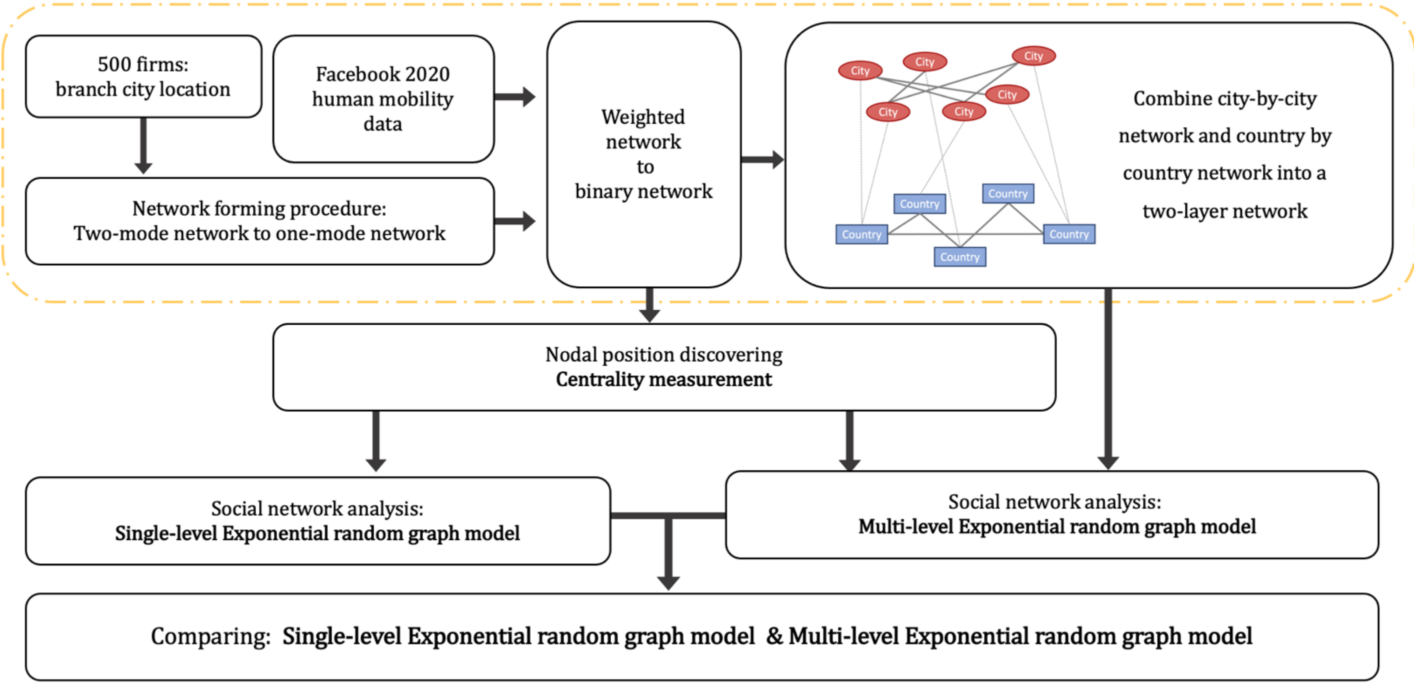

Figure 6 Research frame work

First of all, the first data: the matrix of the branch in a city location (Orbis 500 firm data), which is a two-mode network matrix (firm-city) is transformed into one-mode data by matrix transportation and multiplication; the second data: Facebook human mobility data, which is already an edge network data does not need to be transformed into network data. Secondly, the city and country network data are then transformed into binary networks to fit ERGM, in which the threshold is

doi:10.6342/NTU202203794

selected through sensitivity analysis. The number of branches in each city originally is set as vertex attributes in the city-level network, and GPD and population are set as vertex attributes in the country-level network. Third, to discover the nodal position and network structure, centrality measurement and ERGM are then applied to the two independent networks respectively. Forth, to combine the two networks into a multilevel network, the city nodes in the city-level network are linked to their nationality at the country level. Lastly, multi-level ERGM is applied to the multilevel network to estimate the cross-layer configurations and nodal attributes.

3.4 Method

This study aims to transfer the Orbis branch location data and Facebook mobility into city-by-city and country-by-country network data and combine them into a two-layer network of city-country data. Later on, apply a multi-layer exponential random graph model (ERGM) to examine the network structure and estimate the role of cities. R program is used in the study to conduct data cleaning and model building. In the model building part, package 'multilayer.ergm' is applied to provide multi-layer network analysis (Chen, 2021).

doi:10.6342/NTU202203794

Network formation

The original Orbis data only contains the location of the branches, there ae no direct information for the connections between cities. With the usage of bipartite network for network building aims to convert a two-way model into (i.e. cities and firms), into a one-way model (M. Zhao et al., 2020). A bipartite network can be formally defines as ‘a set of network nodes divided into two disjoint sets so that no links are present between two nodes within the same set’ (Ulusoy, 2015). After transforming the matrix into a city-to-city adjacency matrix with bipartite analysis, the matrix becomes a symmetric matrix. Which can be written as:

$$E(c) = V * V^{t} \tag{1}$$

The origin city-branch matrix is represented as V and it’s transpose matrix as V^{t}, which the row is the city where the branches are located, and the column names are the firm’s name which the branches belong. If one firm has a branch located in the city, the corresponding value in the matrix will be assign as 1, and assigned as 0 when the firm doesn’t have branch located in the city. On the other hand, $E(c)$ represent the one-mode symmetric network (Figure 7).

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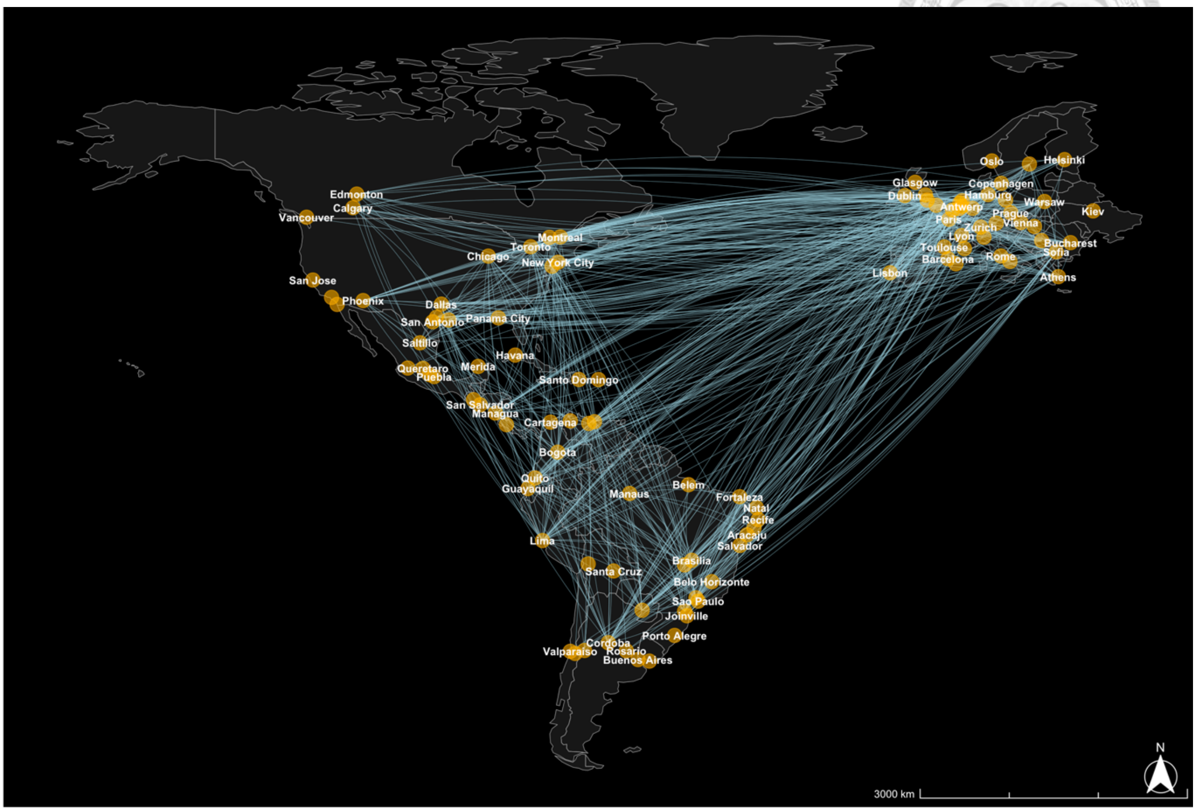


Figure 7 2021 City economic interaction map

Centrality measurement

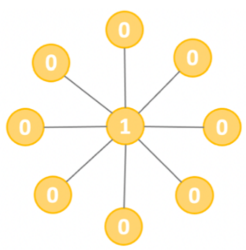
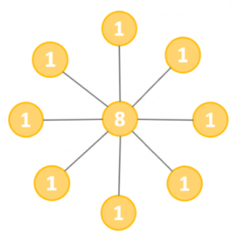
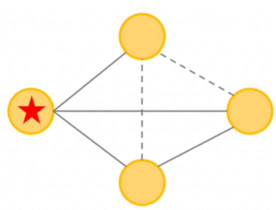
Centrality measurement is a commonly used methodology in social network analysis. Betweenness, degree, hub, and eigenvector index are selected in this study to compare the positionality of cities and countries in the global economic network. A body of studies has applied the centrality measurement for estimating a city position in the city economic network (Campante & Yanagizawa-Drott, 2018; Guo et al., 2020; Sigler & Martinus, 2017). Each of the centrality

doi:10.6342/NTU202203794

measurements seeks to observe the network in different kinds of aspects and quantify the importance of nodes considering the network structures.

Betweenness shows whether the node is in the position of ‘bridge’ in the network, where nodes with a higher value of betweenness represent that it has the shortest path to all nodes compared to others. In short, the shortest path of all paired nodes must pass the node with the highest betweenness value (Neal, 2011). Degree measures the total linkage of one node, and has been widely applied in world city network research to estimate the interlocking branch office network (Derudder & Taylor, 2021; Taylor, 2001). Clustering coefficient is the index describing the clustering effect between nodes, which represents nodes are connected to each other in a group, therefore, representing a clustering groups of nodes (Bonacich, 2007).

Table 1 Centrality measures definition

	Betweeness	Degree	Clustering coefficient
Definition	The node that lies on communication paths and **controls communication flow**	The node that have **more ties to others** may be advantaged position	The node that tends to **cluster** others, creating high density groups of ties
Description	The shortest path from all nodes to all other that past through a particular node	Sum of the linkage the node is connected to	The number of pairs of neighbors are also connected to each other
Example			

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Single-level Exponential random graph model (ERGM)

Exponential random graph model (ERGM) is a statistic model that observed the network structure by estimating the probabilities of the formation of linkages between nodes, including the network dependence effect on nodal and edge attributes. Binary matrix $\mathbf{Y} = Y_{ij}$ represents the adjacency matrix of the interaction between all the nodes, in the case of Y_{ij} =1, linkage exist between node i and node j ; On the other hand, while Y_{ij} =0, there is no edge between node i and node j. Interactions between nodes are fixed and unidirectional, therefore, $Y_{ij} = Y_{ji}$ and matrix Y is a symmetric matrix.

In ERGM, is a stochastic model that assumes networks are based upon different types of structure. To capture the morphology of network, a fix number of exogenous nodes are considered to be incorporate with each other, and statistics are count of the particular subgraph or configurations in the network (Robins et al., 2007). The subgraphs ($\boldsymbol{Q}$) in the network are evidence of the dependence assumption, such as dyadic, triadic mode, or triad closure modes, which will be explained as structure built from two to three cities, and can be interpret as the cities included are considered to have economic interactions. The ERGM model can be specified as:

doi:10.6342/NTU202203794

$$\mathbf{Pr}(\boldsymbol{Y} = \boldsymbol{y}) = \left(\frac{\mathbf{1}}{\boldsymbol{k}}\right) \mathbf{exp}\{\boldsymbol{\Sigma}_{\boldsymbol{Q}} \boldsymbol{\eta}_{\boldsymbol{Q}} \boldsymbol{Z}_{\boldsymbol{Q}}(\boldsymbol{y})\} \quad (2)$$

Where $\boldsymbol{\Sigma}_{\boldsymbol{Q}}$ is the subset of all the included configuration $\boldsymbol{Q}$; $\boldsymbol{\eta}_{\boldsymbol{Q}}$ will be the corresponding parameter of $\boldsymbol{Q}$; $\boldsymbol{Z}_{\boldsymbol{Q}}$ is the statistic result corresponding to the assigned configuration $\boldsymbol{Q}$, indicating if $\boldsymbol{Q}$ can be observed in network $\boldsymbol{Y}$; $\boldsymbol{k}$ would be the normalized coefficient to ensure $\mathbf{Pr}(\boldsymbol{Y} = \boldsymbol{y})$ has a proper probability distribution.

Three types of parameters can be included in ERGM: First of all is the structural effects, which is the main idea of the model, to estimate the interdependence of the included structures. Secondly, the nodal covariates are account to show the effects of nodal attributes. In this study for instance, the nodal covariates will be used to show whether two cities have similar number of the branches located in the city and causing the model to have a higher probability of forming linkages. Lastly, the dyadic covariate explains the effect of different network to the formation of a network. For example, how human mobility effects city economic network (Smith et al., 2019).

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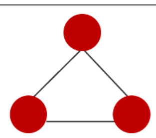
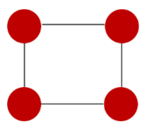
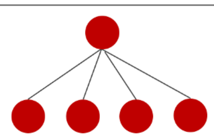
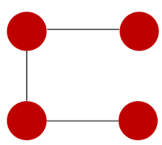
Single-level network configurations

Table 2 shows the selected configurations in the single-layer ERGM model, where the nodes in the configuration are all cities in the city economic interaction network. *Triangle* and *4 cycle* are two similar structures where the cites in the structures are linked as a group and connected as a cycle, all the cities in the structure have even positionality in the structure. *4 stars* shows the structure that a central city is linked to four other cities, showing that there is a dominating city among leading the economic interactions between cities. Three-way clustering shows the structure where 4 cities are linked as a line, which showing the cities also have even power to the network, but not as clustering as the cycle structures.

Table 2 Single-level ERGM configurations

Configurations	Structure	Economic interpretation
Triangle		Cities that are connected in a group of three, may strengthen the linkage
4 cycle (4C)		Cities that are connected in a group of four, may strengthen the linkage
4 stars (4K)		A certain city is connected to some cities and is dominating the city economic interaction
Three-way clustering (3W)		Cities that are linked together as three have high effect to the economic interaction network

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Multi-level ERGM

This study aims to apply Multi-level ERGM to the human mobility and city-economic network, the two network each represents different network and Multi-level ERGM will be able to observe the network structure *across* and *within* network.

The relationship between human mobility and city economic interaction can be explained by the combination of two sperate networks into one with multiple layers, and examine the different structure (Lazega & Snijders, 2015; Wang et al., 2016). Multi-level ERGM is capable of distinguish the layers the nodes belongings and seen them as different characters in the network. With observing the role and positionality of different cities, this study is able to interpret: How will the positions and role cities display, under the effect of business travel in different countries.

With the theory of hierarchical network, multi-level ERGM analysis the conjunction between two networks and assume them to be independent to on another (Wang et al., 2013). The first data, business travel country-by-country network is set as the first layer (A), and world city network is set as the second

doi:10.6342/NTU202203794

layer (B), the two layers are then linked through the belonging of city, where the city node will be linked to its corresponding belonging country and be identify as cross-layer network (X) (Figure 8). Therefore, building matrix A, B, X and $\mathbf{Pr}(\boldsymbol{A} = \boldsymbol{a}, \boldsymbol{B} = \boldsymbol{b}, \boldsymbol{X} = \boldsymbol{x})$ will be the probability of the formation of linkage in the three networks, which is also the dependent variable in multi-level ERGM. The model is specified as:

$$\mathbf{Pr}(\boldsymbol{A} = \boldsymbol{a}, \boldsymbol{B} = \boldsymbol{b}, \boldsymbol{X} = \boldsymbol{x}) = (\mathbf{1}/\boldsymbol{k}) \,\mathbf{exp}\{\textstyle\sum_{Q,\Lambda} \boldsymbol{\eta_Q Z_Q(a)} + \boldsymbol{\eta_Q Z_Q(x)} + \boldsymbol{\eta_Q Z_Q(b)} + \boldsymbol{\eta_Q Z_Q(a,x)} + \boldsymbol{\eta_Q Z_Q(b,x)} + \boldsymbol{\eta_Q Z_Q(a,x,b)} + \boldsymbol{\eta_\Lambda Z_\Lambda(a,x,b)}\} \quad (3)$$

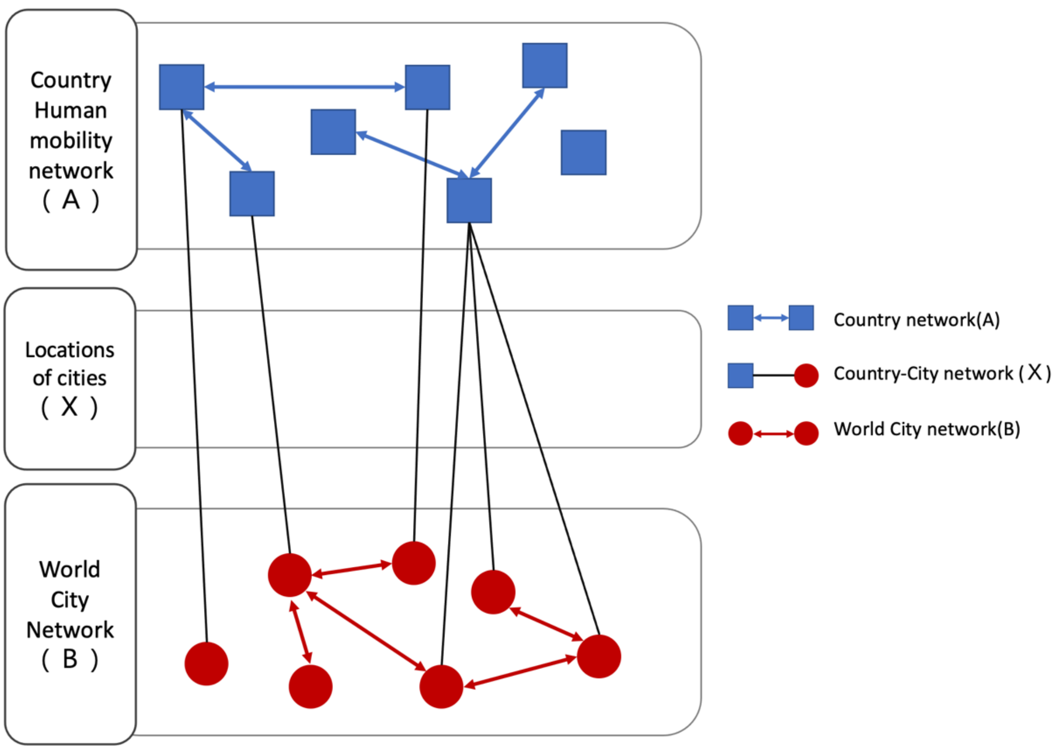


Figure 8 City-country multi-level network

doi:10.6342/NTU202203794

Where:

$\boldsymbol{\eta_Q}$ is the corresponding parameter for configuration $\boldsymbol{Q}$ (4-stars, triangle, 4-cycle and Three-way clustering)

$\boldsymbol{\Lambda}$ is the nodal attributes variables (GDP, population)

$\boldsymbol{Z_Q(a)}$ and $\boldsymbol{Z_Q(b)}$ are the statistics for Country-network $\boldsymbol{A}$ and City-network $\boldsymbol{B}$, considered significant when the value is positive, meaning that $\boldsymbol{Q}$ is easily found in the network

$\boldsymbol{Z_Q(x)}$ is the statistics for cross-layer network $\boldsymbol{X}$

$\boldsymbol{Z_Q(a,x)}$ and $\boldsymbol{Z_Q(b,x)}$ are the statics for interaction between $\boldsymbol{A}$ and $\boldsymbol{X}$ networks, $\boldsymbol{B}$ and $\boldsymbol{X}$ networks respectively

$\boldsymbol{Z_Q(a,x,b)}$ represents the statistics of configuration $\boldsymbol{Q}$ in all the three networks

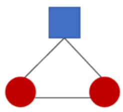
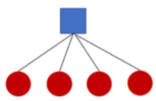
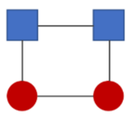
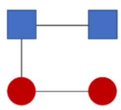
Multi-level network configurations and attributes

Configurations in multi-level ERGM spans across different levels, involving the business travel linkage and the intracity firm ties. The selected configurations are displayed in Table *3*, along with its corresponding economic interpretation. The configurations listed allow to have a further understanding of the structure and estimate the configurations that can create more potential linkages in the networks.

doi:10.6342/NTU202203794

The *triangle* configuration tests whether two cities are more likely to exit interactions when they belong to the same country. *4 stars* shows the more the cities belong to the same country, the more they are likely to connect to other cities in with other nationality. *4 cycle* indicates that, when the nationality of a pair of cities are linked through business travel, they have a higher possibility with economic interactions. *Three-way clustering* shows that, either it's within layer or cross layer, nodes are possible still connect with each other through mutual nodal linkages.

Table 3 Multi-level ERGM configurations

Configurations	Structure	Economic interpretation
Tringle		Cities in the same country has a higher connection
4 stars (4K)		Multiple cities belongs to the same country
4 cycle (C4)		Cities in different country share similar attribute, so as the countries
Three-way clustering (3W)		Links are more likely to exist when countries are linked to others

doi:10.6342/NTU202203794

Chapter 4 Result

In the network building procedure, city economic network and human mobility network are both originally a weighted network, where the flows represent the number of branches between two cities and the volume of mobility between two countries respectively. To transform the two weighted network into binary network, sensitive analysis is first applied to the data, where quartiles (first quartiles, third quartiles, median values) are set as the threshold for transformation, the result shown in the Appendix have similar performance, as a result, median values are chosen to set as the threshold for both of the network.

4.1 Descriptive analysis: centrality measurement

From Figure 9 to Figure *11* shows the spatial distribution of cities in the three centrality measurements, the size of the nodes represents the value of the measurement index.

First of all, Figure 9 shows the betweenness value of the cities selected. Betweenness shows the level of the city's ability of leading the global economic, which can be explained as the role of 'bridge' each city represents. The spatial distribution shows that cities in the North America and Europe have a higher value

doi:10.6342/NTU202203794

on average, showing that most cities in develop regions play more important roles in the network structure, such as: Los Angeles, Phoenix, New York City, London and Paris. In this case, cities with the significant in betweenness shows the dominating role of countries when the city with higher betweenness value represents the impact of countries, especially they connect the cites in different

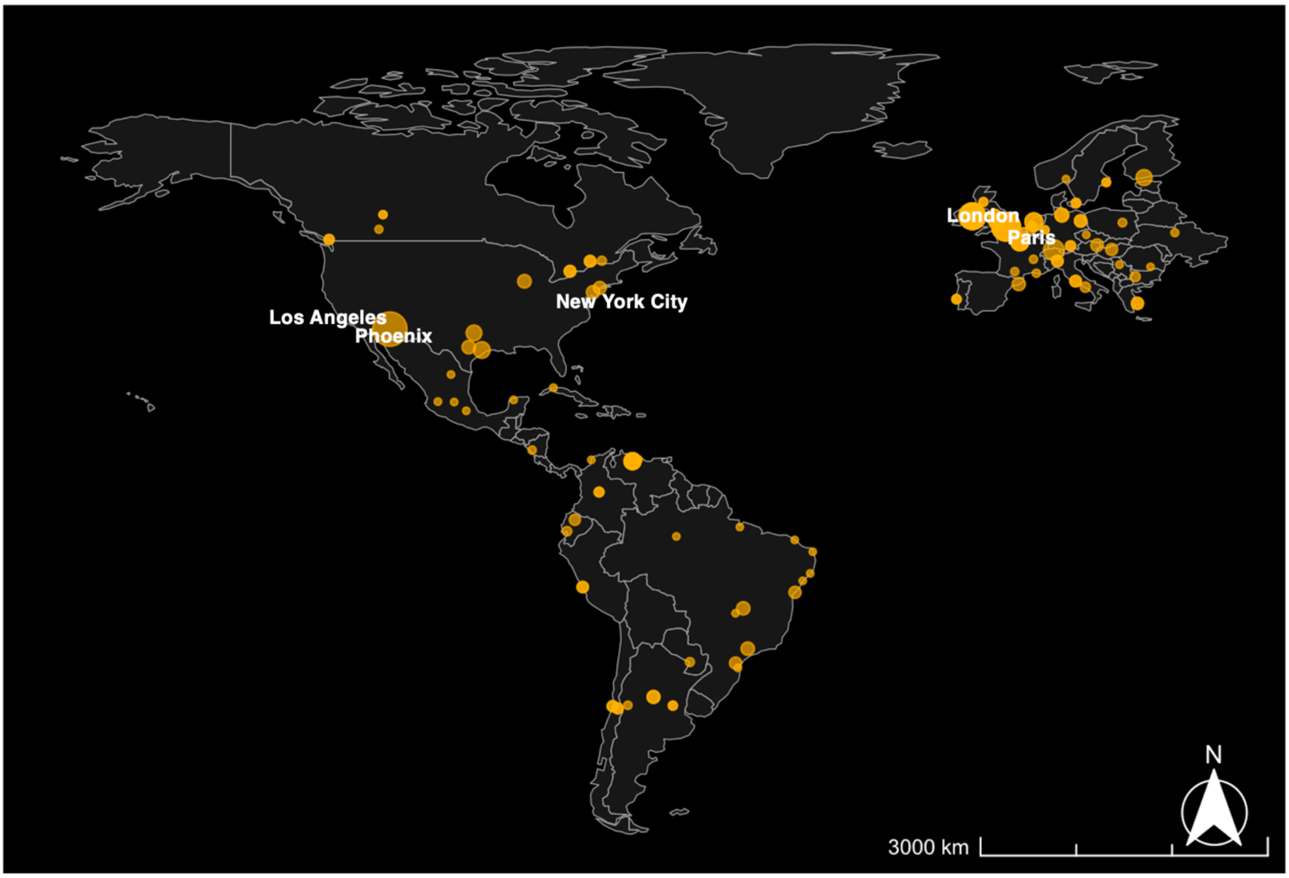
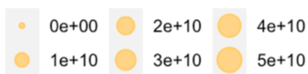


Figure 9 Centrality measurement: Betweenness



region and countries.

Secondly, Figure 10 shows the degree measurement, in which the higher the degree is, the more linkage the city is connected. The most significant difference between

doi:10.6342/NTU202203794

degree and betweenness, is that degree does not represent the role of bridge but the level of interaction between the cities. From the result, it can be concluded that city with high level of betweenness also have a high level in degree, however cities with higher level of degree is not certain to also have a higher level of betweenness. For example, based on the result of betweenness, where cities mostly have higher level in both betweenness and degree, cities such as Milan, Rome, Athens and Dallas also have a significant result in degree but not having a significant result in betweenness. In short, the cities that simply only have high level in degree are not able of dominate the economic interactions between cities, but their present may

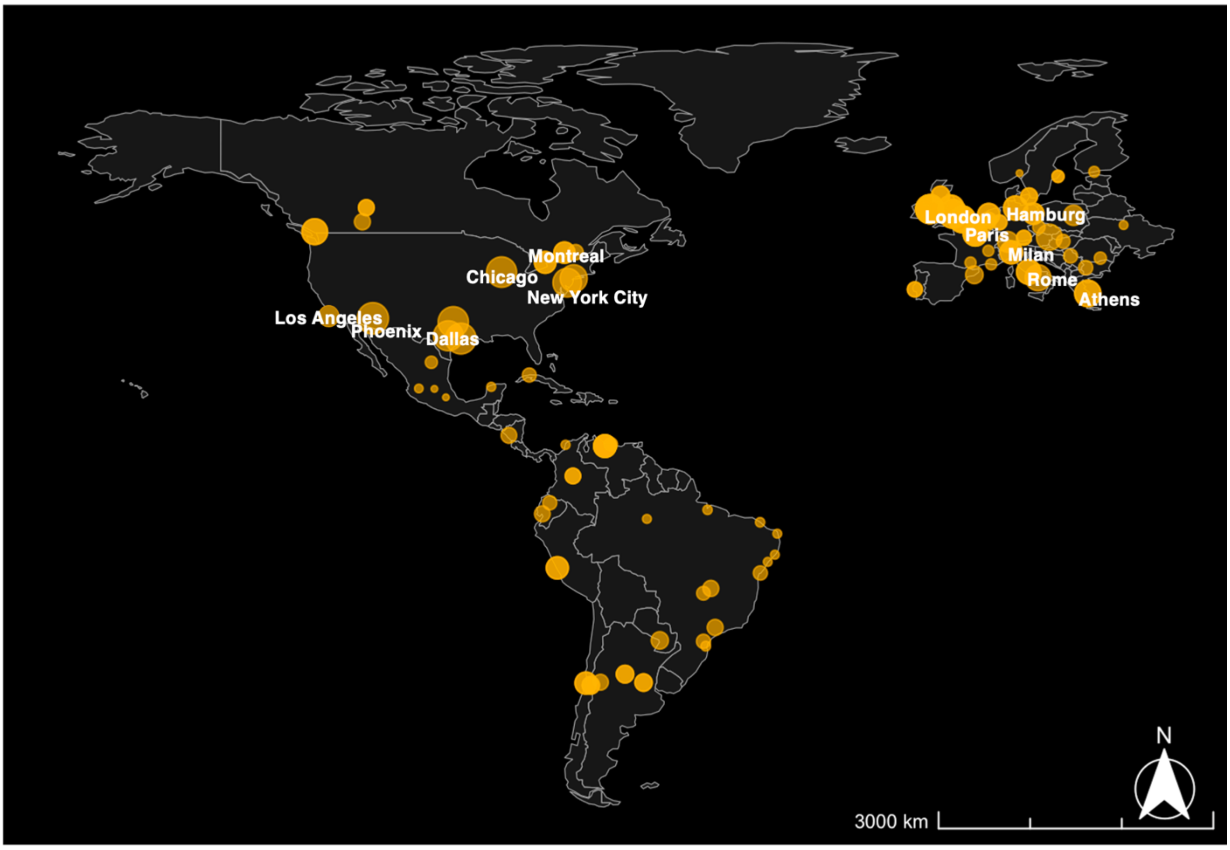


Figure 10 Centrality measurement: Degree

doi:10.6342/NTU202203794

increase the density of the networks between cities, and create interactions between cities. After all, it is also worth noticing that cities with higher level in both degree and betweenness are located in the North America and Europe.

Third, Figure *11* distributes the clustering coefficient of each city, cities with a higher clustering coefficient represent that it locates in the center of a group of connected cities, in which the cities that are connected to a certain one are also connected to each other. Different from betweenness and degree, cities in North America have a relatively lower value of clustering coefficient, and the cities in South America significantly have a higher value. The above status indicates cities

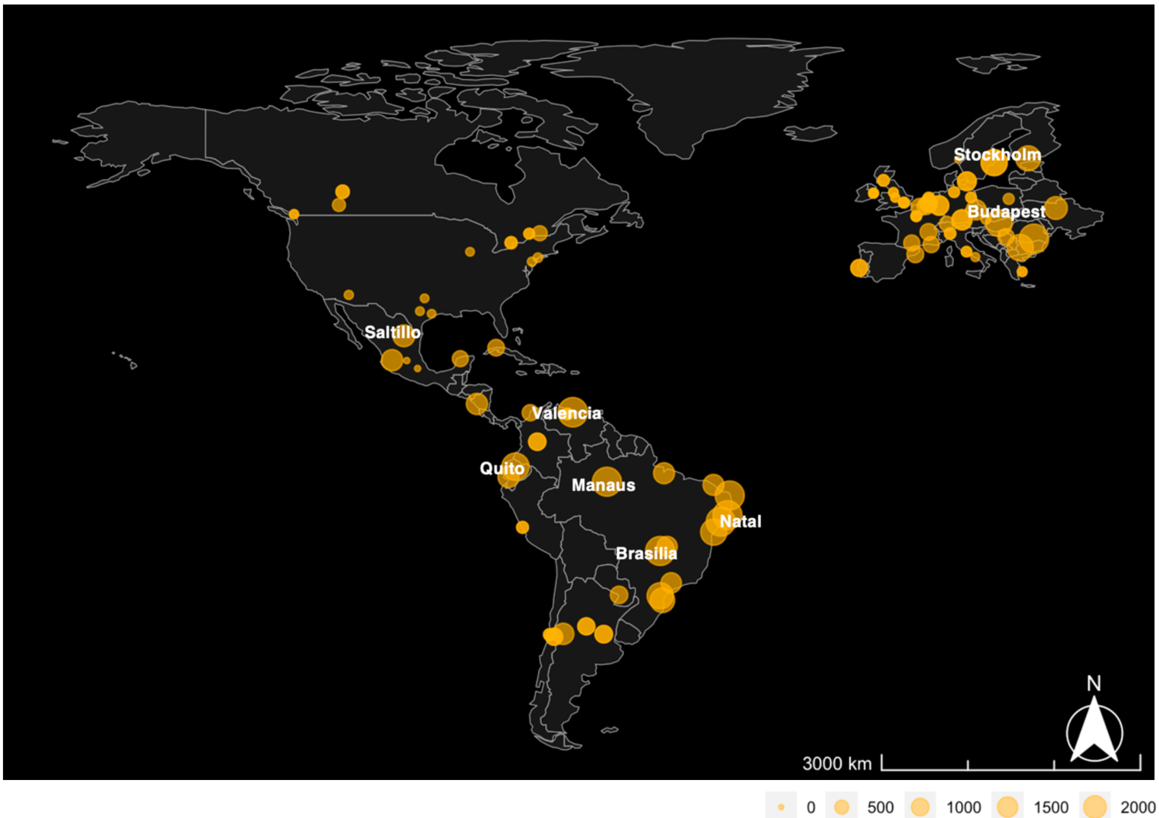


Figure 11 Centrality measurement: Clustering coefficient

doi:10.6342/NTU202203794

in South America are mostly connected to each other, and cities in North America have a larger portion linked to cities located in another part of the cities. In short, South American cities are more concentrated, and North American cities' connections are more separated. Meanwhile, European cities also have a higher value of clustering coefficient than others, in spite of that, West European cities have a higher value of degree and betweenness, and East European cities have a higher clustering coefficient than West European cities. Therefore, it can conclude that the cities with a higher value of clustering coefficient often have a lower value of betweenness and degree.

To sum up, cities in the North America region mostly play the vital role in the city economic network structure, and European cities often connect to cities in the same region.

4.2 Single layer: City economic interaction ERGM

Table *4* shows the result of single-layer ERGM applied on City economic interaction network, the model includes the total number of branches located in the city and three different kinds of centrality measurements as nodal attributes.

doi:10.6342/NTU202203794

The four aforementioned structure in Table 3 are also included as morphology measurement in the ERGM model.

The nodal attribute branch number shows a significant result, where the more offices of multinational firms are located in a city, the higher the possibility of linkage formation is in the city economic network. This matches the expectation of location strategies of multinational firms that office creates knowledge flows and causing cities to crate economic interaction.

On the part of centrality measurement, clustering coefficient and betweenness have significant result but only betweenness has a positive effect. The positive effect of betweenness shows that the role of ‘bridge’ in the network is relatively important, meaning some cities are more important than others when they connect other cities with each other. Therefore, cities need to be connected by a certain ‘hub’ city in the network to increase the density of the global city network. On the other hand, although clustering coefficient also has a significant result, it has a negative effect to the model. This can be explained that, local clustering will not provide positive effect to the global network, in other words, when networks mostly clustered in certain few groups it might loosen the density of the

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comprehensive network, thus, can also be interpret as a global connection needs to be built.

In the four morphologies included in the model, 4 star and three-way clustering have significant results. First of all, the 4 star structure has a positive effect to the model, showing that a dominate city plays an important part in a group of a city, which represents the commend points in *The Global City* (Sassen, 1991). This also reflects the positive result of degree, where some certain cities play an important role in the network structure that connects cities located in different part of the network. Secondly, three-way clustering is negatively significant, showing that when cities are lined up with a group of four, it has a negative effect to the network, meaning the cities in the economic network need a dominate city to lead the economic action of the other cities.

Table 4 City economic network ERGM model result

	Variable types	Variables	Coefficient	Z-value	P-value	
City economic network	*Nodal attribute*	Edges	-4.237E+00	-112.3	<1e-04	***
		Branch number	5.070E-04	3.728	0.000193	***
	Centrality measurements	Clustering coefficient	-2.736E+00	-2.737	0.006202	**
		Degree	-1.153E-04	8.156E-05	-1.414	
		Betweeness	1.902E-04	2.979	0.002893	**
	Network morphology measurement	4 star	0.0019936	2.165	0.0304	*
		triangle	0.4616316	1.238	0.2158	
		cycle4	0.0172466	0.870	0.3841	
		Three-way clustering	-0.0128250	-4.309	<1e-04	***

Significant sign: *p < 0.1; **p < 0.05; ***p < 0.01

doi:10.6342/NTU202203794

4.2 Multi-layer: Multi-level ERGM estimation

Table *5* gives the result of from multi-level ERGM, which includes four different parameters: edges from country-level and city-level network and their covariance, nodal attributes of countries, nodal attributes of cities, cross-layers configurations defined in Table *3*.

The first part would be the nodal attributes of both of the level, including country-level and city-level network, which includes the socio-economic variables GDP and population, and the total number of branches. The significant result of GDP (0.005868) indicating the level of economic development of countries is dominating to the city-level economic interactions, which matches the hypothesis of this study. In short, the location of firm subsiders depends on the GDP level of the belonging country in certain part, furthermore effecting the formation of ties between cities. The next part would be the city-level nodal attributes including the total number of branches located in a city and the selected centrality measurement. The positive effect of total branch number has the same result as the single-layer ERGM, showing that either with or without the intervention of countries, the location strategy always plays an important role in the economic interaction between cities. Indicating, either in the single-layer network or two-layer network,

doi:10.6342/NTU202203794

the developing level of cities is highly correlated to both the business travel linkage and city economic interaction linkages. The more the branches are located in the cities, the higher possibility of the linkage formation is in all layers of the network (within layer: city-level, cross-layer: country-city).

The second part would be the centrality measurements, the clustering coefficient centrality measurement appears to be positive significant in the country-level but negative significant in the city-level. Indicating, the power of country groups is still higher than cities. In other words, the local clustering between countries can be explained as the power of countries linked as a group, which will trigger the economic interactions between cities. Therefore, it appears that countries have power over city-level economic interactions. The centrality measurement degree has similar result as clustering coefficient, which can also be interpret as countries with more dominating power and the more countries it is linked to may create more possibility for city to form city level economic interaction.

The last part is the model result of the four morphologies in the network, all four structures are cross-layer structure, which represents that cities are linked to countries based on its nationality, configurations are set to estimate the cross-layer network structure, and include both nodes from city-layer network and country-

doi:10.6342/NTU202203794

layer network and are displayed in *Table 3* Multi-level ERGM configurations. *Cycle 4* is the one and only configuration that has positive significant effect to the network, and it represents the concept when two countries have business travel linkage, cities in the two countries are more likely to connect to each other. Which answers the target of this study: countries have power over cities, where cities will follow the linkages or configurations in country-level. In other words, countries have strong power over cities, it can dominate city interactions in certain level.

Table 5 Multilevel ERGM results

	Variable types	Variables	Coefficient	Z-value	P-value	
Multi-level ERGM		edges_layer.1	-3.5556580	-7.377	<1e-04	***
		edges_layer.2	-0.3598868	-5.216	<1e-04	***
	Country level Nodal attribute	Population	-6.441E-01	-3.834	0.000126	***
		GDP	4.534E-01	2.755	0.005868	**
	Country level Centrality measurements	Clustering coefficient	7.029E+03	4.689	< 1e-04	***
		Degree	1.335E-04	4.554	< 1e-04	***
		Betweeness	-8.552E-04	-1.503	0.132806	
	City level Nodal attribute	Branch number	1.429E-03	2.435	0.014900	*
	City level Centrality measurements	Clustering coefficient	-6.122E+01	2.597E+01	0.018395	*
		Degree	-1.023E-03	-2.374	0.017608	*
		Betweeness	-0.0012882	-4.859	<1e-04	***
	Network morphology measurement	4-star-layer	-Inf	-Inf	<1e-04	***
		triangle	-3.695E-01	-5.106	<1e-04	***
		cycle4	2.894E-02	2.715	0.00663	**
		Three-way clustering	-3.815E-01	-1.885	0.05936	*

Significant sign: *p < 0.1; **p < 0.05; ***p < 0.01

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Chapter 5 Discussion

From the above result, the significance of this study can be concluded in three points. First of all, the city economic interaction network is highly influenced by the country business travel network: not only the centrality measurement index of the country nodal is more significant than the city level, but also the cross-layer morphology Cycle 4 also shows a positive significant result. Therefore, it can be concluded that the power of the country over the city is still inevitable in the network combined country-level and city-level networks. Secondly, instead of simply setting country as one of the nodal attributes of a city node, the relationship between country and city should be considered as an independent layer in the hierarchical structure. Creating linkage between cities with their belonging country in a multi-level network distributes the direct interaction and structure between cities and countries, which shows the direct effect of the power of a country's interaction on city interactions. Third, the nodal attributes either in the country or city are both influencing the connection in the network. Where country attribute GDP and city attribute total number of branches in a city both have a positive effect on the network, indicating that the higher the economic

doi:10.6342/NTU202203794

development level in the country, creates the higher possibility of connections between countries and cities.

This study created linkages between the country network and city network based on the city's nationality, with the structure included in the model, it appears that city linkage is powered by country linkage. In other words, the formation of economic interaction between cities depends on the linkage between its belonging country's connections. Scholars have conducted study in the topic of the power of country to regional government and regional economic development (Agranoff & McGuire, 2003; Gereffi & Korzeniewicz, 1994; Olberding, 2002; Schneider et al., 2003; Shrestha, 2010), different level of governments are combined in a network through a network survey to identify their interactions(Y. Lee et al., 2012), international firms are also connected to countries based on their ownership (Smith et al., 2019). Previous studies have concluded that regional governments are highly dominating the social and economic interaction between regional governments and organizations. In this study, with the significant result of the centrality measurement index of country nodal and Cycle 4 structure in the multi-level ERGM analysis, it can be concluded that with the hierarchical structure included, the power of countries to cities are even more clear. In short, the discovery of this

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study lined up with the previous research that a country can be dominating to the city, but with a better understanding of the network formation aspect.

Literatures have pointed out that socio-economic variable GDP and population represents the economic development of countries and include them as nodal attributes in network analysis (Chong & Pan, 2020; Smith et al., 2019), and stated that they both have a positive significant performance in the model. GDP and population are also included in this study as the nodal attribute of the country-level network, however, only GPD appears to have a positive impact on the network and population showed a negative effect. This indicated that, with the cross-layer network analysis, country GDP still lines up with the previous studies, which has a positive impact on the economic interaction and the linkage forming between cities and countries. On the other hand, after combining country-level and city-level network, the population in the country no longer boost the linkage between cities, which points out between GDP and population, GDP is more convincing while attempting to describe the economic status of a country and its power over cities.

As for the limitation of this study, first of all, this study constrained the study area to the Americas to Europe (excluding Russia), this might neglect the linkages

doi:10.6342/NTU202203794

between Asia and America. Also, without the linkage in Asia and other continents, the positionality of cities and countries can also be misestimated, the result of morphology and nodal attributes might have a different result if including the comprehensive global network. Secondly, to match the requirement of ERGM, the weighted networks (human mobility volume and number of branches between cities) are transformed into binary networks, even though centrality measurements can substitute the weighted linkage at a certain level, without the weighted linkage, the impact of linkage can still be underestimated. Third, the source of human mobility data is based on the Facebook dataset. The human mobility volume might also be underestimated while there is still a certain amount of the population who are not Facebook users, therefore are not included in the data. Lastly, even though multi-national firms follow the strategies of location, the ownership of firms and their' headquarters' location or its industry can also affect the network formation of the city's economic network. The location of the branches might also be skewed based on the firm collected in the Orbis data.

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Chapter 6 Conclusion

The hierarchical structure performed well in the two-layer network formed by the city economic interaction network and country business travel network. With applying ERGM to both single-layer city economic networks and multi-layer city and country networks, structure and nodal attributes performed differently in the two models. The significant result of the four selected configurations shows the impact of the cross-layer effect on the model, where the linkage of human mobility between countries can influence the economic interaction between cities. Moreover, the significant centrality measurement index shows the independent structure in both of the networks can influence the combined multi-layer network. The centrality measurements in country nodal have the best performance among the two layers, which also demonstrates the dominating role of countries in cities. Lastly, GDP has a positive significant result unsurprisingly, but the population has a negative significant result, which is the most surprising discovery.

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Appendix

Table 6 First quartile threshold

	Variable types	Variables	Coefficient	Z-value	P-value	
Multi-level ERGM		edges_layer.1	-4.513620	-45.301	<1e-04	***
		edges_layer.2	-4.137737	-48.816	<1e-04	***
		edgecov.layer.1.cov	-5.050819	-4.749	<1e-04	***
		edgecov.layer.2.cov	50.669258	31.154	<1e-04	***
	Country level Nodal attribute	Population	-0.23384	-0.027	0.978	
		GDP	4.626E-01	2.704	0.00685	**
	City level Nodal attribute	Branch number	5.070e-04	3.728	0.000193	***
	Network morphology measurement	4-star-layer	-Inf	-Inf	<1e-04	***
		triangle	8.24056	0.309	0.758	
		cycle4	0.34163	1.711	0.0871	*
		Three-way clustering	-Inf	-Inf	<1e-04	***

Significant sign: *p < 0.1; **p < 0.05; ***p < 0.01

Table 7 Third quartile threshold

	Variable types	Variables	Coefficient	Z-value	P-value	
Multi-level ERGM		edges_layer.1	-4.5333	-30.995	<1e-04	***
		edges_layer.2	-3.7934	-21.624	<1e-04	***
		edgecov.layer.1.cov	-6.0865	-4.614	<1e-04	***
		edgecov.layer.2.cov	69.3289	34.813	<1e-04	***
	Country level Nodal attribute	Population	-0.1751	-0.753	0.452	
		GDP	0.1386	0.600	0.548	
	City level Nodal attribute	Branch number	0.2802	2.141	0.0323	**
	Network morphology measurement	4-star-layer	-Inf	-Inf	<1e-04	***
		triangle	1.307E+00	0.128	0.898	
		cycle4	0.8595	1.589	0.0871	
		Three-way clustering	-Inf	-Inf	<1e-04	***

Significant sign: *p < 0.1; **p < 0.05; ***p < 0.01

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