

Multiplex urban networks in the Yangtze River Delta:
Spatial patterns and their explanatory factors

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Multiplex urban networks in the Yangtze River Delta:
Spatial patterns and their explanatory factors

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PREFACE

My interest in urban studies stretches back to my postgraduate studies in urban geography in the Chinese Academy of Sciences. Looking back at this, the most powerful influence on my scientific career was that, as a research assistant, I participated in dozens of research projects on regional and urban spatial development, which enabled in-depth fieldwork in more than five provinces and twenty mega-cities, as well as in-depth interviews with government officials, urban planners, and entrepreneurs. These experiences made me realise how urban systems are organised in reality. I was shocked by the intense intercity competition, as opposed to cooperation. A typical case was the conflict around the site selection of a proposed airport within the Suzhou-Wuxi-Changzhou cluster, in which each city maximised their own interests, and simply ignored the interests of others. These experiences fuelled my interest in investigating regional organisation in the context of ongoing economic, societal, and governance changes in China. This is also the reason why I joined Professor Ben Derudder's group in Belgium, so I could narrow my academic focus to urban networks for my PhD.

Four years ago, I started my PhD with full confidence and enthusiasm, but it quickly turned out to be a tough journey, with occasions of sadness and self-doubt. Before this, I had thought that I was fit for scientific research; I even thought that I was good at it. The evidence that granted me this childish confidence was my publication of seven peer-reviewed papers in decent Chinese journals during my undergraduate studies, which far surpassed the average for Master's students in China. When I drafted my first paper in English, however, I received a lot of critical comments and the paper was initially rejected by journals. These gradually dawned on me that perhaps I did not completely understand what research is, and how to do it. At that moment, I was confused. All of my agonies, sadness, and self-doubt, however, compelled me to look at my own ignorance and re-learn how to conduct *genuine* scientific research step by step. This dissertation is the result of this long process.

I cannot talk about the process of how I came to re-understand scientific research without mentioning the valuable role of my supervisor, Professor Ben Derudder. Although acknowledging the assistance of supervisors is the standard procedure in

writing the preface of dissertations, here I would like to define the impact of Ben on my PhD, and especially on my academic career. First, Ben taught me how to define a research problem, find a solution to it, and then defend it. His critical comments always hit the nail when exposing existing problems in my research, and his rigorous demands brought about subtle changes that helped me better frame my research. Second, Ben taught me what a researcher should be like. Modifications throughout entire pages, and even more than 10 rounds of comments for each of my manuscripts, taught me that a researcher should be responsible for each of his/her arguments, sentences, and words. Additionally, I am grateful for the time and energy he devoted to my research: the exchange of more than 1200 emails, and the patient drafting and sending of the recommendation for my job application from a ski resort with a weak Wi-Fi signal, are particularly memorable and impressive.

I would also like to express my sincerest gratitude to Professor Frank Witlox. Frank's heartening smile, encouraging words, and generous support, always inspired me to move forward. I learned a great deal from him, not only about how to be a renowned scholar, but also about how to lead an excellent team.

This thesis would not exist in its current form without the support of other academic partners. I would like to offer my special thanks to Dr Jianghao Wang, from the Chinese Academy of Sciences, who helped with many concrete technical questions, and gave invaluable inspiration. His expertise in driving data and programming tailored methods, and his valuable commitment towards the research, were of significant influence on the shaping of many of the chapters presented in this dissertation. I thank Dr Lei Wang, from the University of Manchester, for our helpful discussions, and Professor Ming Tong, from Tongji University, for generously sharing the manuscript of Friedmann's new paper. In addition, I thank Dr Hui Zhou (Chinese Academy of Sciences, Nanjing), and Zhichao Xue (Chinese Academy of Sciences, Beijing), for providing invaluable help with data collection. There is also a list of scholars I would like to acknowledge for their help and support in my nascent academic career: Dr Yingcheng Li (University College London), Dr Wenjie Wu (Heriot-Watt University), Dr Miaoqi Zhao (South China University of Technology), Dr Xingjian Liu (the University of Hong Kong), and Professor Xuejun Duan (Chinese Academy of Sciences, Nanjing).

I wish to express my gratitude to my (ex-) colleagues at the SEG-group, and the Department of Geography in Ghent University, in particular, Elien, Filipe, Freke, Galuh, Helga, Jonas, Jorn, Karine, Leen, Lu, Tom, Veronique, and Zhan. I owe thanks to my (ex-) office-mates for their great help with a series of living and studying problems, for our interesting and inspiring chatting, and for their creation of an amicable environment. I also would like to express my gratitude to all of my love-hate Chinese colleagues, my deepest appreciation for your support, encouragement, and company. The ‘hate’ is because it was our intimacy that caused me to hide in the tender world of our cluster of Chinese students. Special thanks go to Liang, Longxing, Jiayun, Shengrun, and Xinyi: thanks for your companionship during this journey.

I sincerely acknowledge the financial support of China Scholarship Council (CSC) and the Special Research Fund of Ghent University (BOF), which enable me to complete my Ph.D. in Belgium.

Wow, I have finally come to the end of this journey. Looking back on it, I actually only did one piece of work: transforming from a research path with Chinese characteristics, to an international research path. The former is more like government-requirement-driven, project-driven, data-driven, methods-driven, and even publishing-papers-driven, while the latter is research-in-itself-driven. Although moving from the former to the latter is not easy, and I am not yet qualified to be an international researcher, at least I am on my way.

Finally, I dedicate this dissertation to my family and my girlfriend.

Weiyang Zhang

Ghent, September 2017

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List of Abbreviations

API	Application Programming Interface
CC	Chongqing-Chengdu Cluster
CPER	Central Plains Economic Region
CSLRPs	Central State-led Regional Plans
CGZ	Central Guizhou Cluster
CYN	Central Yunnan Cluster
CZT	Changsha-Zhuzhou-Xiangtan Cluster
DI	Dominance Index
ESPON	European Spatial Planning Observation Network
FDI	Foreign Direct Investment
GPN	Global Production Network
GaWC	Globalisation and World Cities Research Network
HSR	High-Speed Railway
<i>Hukou</i>	Household Registration System
INM	Interlocking Network Model
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
JJJ	Jing(Beijing)-Jin(Tianjin)-Ji(Hebei) Cluster
LBSM	Location-based Social Media
MHURD	Ministry of Housing and Urban-Rural Development
NCCs	National Central Cities
NDRC	National Development and Reform Commission
NMI	Normalized Mutual Information
PRD	Pearl River Delta
PECA	Physical–Economic–Cultural–Administrative
PURs	Polycentric Urban Regions
PI	Polycentricity Index
PS	Producer Services
PSMDA	Plan for Sunan Modernisation Demonstration Area
RPNM	Regional Plan for Nanjing Metropolitan
RPYRD	Regional Plan for the Yangtze River Delta
PYL	Poyang Lake Cluster

QAP	Quadratic Assignment Procedure
SNA	Social Network Analysis
SD	Standard Deviation
SP	Stepwise Polycentricity
VGI	Volunteered Geographic Information
WH	Wuhan Cluster
WJ	Wanjiang Cluster
WCN	World City Network
YRD	Yangtze River Delta
YREB	Yangtze River Economic Belt
YUADP	YRD Urban Agglomeration Development Plan

1. Introduction

Each of the thirty member cities of this conurbation (the Yangtze River Delta) are open spatial systems that are connected to a constellation of cities world-wide in overlapping social, economic, and political networks. To make this statement is easy but to measure and map these networks is difficult if not impossible. But within China as a whole, the Delta (the Yangtze River Delta) is merely one urban assemblage among several, all of which are ultimately subject to political decisions from the central government in Beijing. (Friedmann, 2017: 58)

1.1 Main objective of the dissertation

As the world's most populous and rapidly urbanising country, China has been witnessing the rapid development of city-regions, mega-city regions and megaregions alike – a new spatial form of cities merging into wider spatial configurations. Typical examples include the rise of the Yangtze River Delta (YRD) around Shanghai, the Pearl River Delta (PRD) around Hong Kong, and the Jing(Beijing)-Jin(Tianjin)-Ji(Hebei) cluster (JJJ) around Beijing. A common and key characteristic of these regional organisations is that multiple and more or less physically separate cities are functionally connected to each other. Such interconnected and polycentric formation has been well documented in Western literature, particularly in Europe (cf. Dieleman and Faludi, 1998). Although these emerging mega-city regions in China provide another laboratory to observe the formation of megaregions, their polycentric and networked development is relatively under-researched.

This dissertation aims to help filling this gap by offering systematic, empirical analyses of the multiplex network formation within the YRD, perhaps the archetypal mega-city region in China. By mapping three kinds of intercity linkages – transport infrastructure links, business interactions and intercity mobility – this dissertation aims to analyse their spatial patterns, assess how this relates to polycentric development, and explore the underlying factors behind these patterns.

A series of contextual factors that relate to the formation of spatial patterns within megaregions in China, such as the stronger effects of administrative borders (Ma, 2005), a specific ingrained political economy (Cartier, 2013), remarkable regional inequality (Wei, 1999), considerable geographical extent and fragmented spatial organisation (Chen et al., 2013) are embedded into the analyses. These empirical results will bring a comprehensive understanding of the structure of urban networks within the YRD (and other Chinese mega-city regions in general) and the reasons behind their formation.

The remainder of this introductory chapter is organised as follows. First, I present the conceptual background of this study, which consists of two aspects: a burgeoning urban network studies literature, and research on emerging mega-city

regions in China. I then formulate the dissertation’s main research questions in light of these literatures. The subsequent section introduces the study area and data, after which the final section outlines the organisation of this dissertation.

1.2 Background

1.2.1 A burgeoning urban network literature

Urban network studies have become a major branch of urban and regional studies and have experienced a rapid proliferation in the academic literature since the 1950s (Figure 1.1). The proliferation of research into urban networks has manifested itself in two aspects: the increased popularity of ‘network thinking’ in theoretical terms (Castells, 1996; Shearmur and Doloreux, 2015) and the rapid development of network analysis in analysing urban/regional systems (Newman et al., 2011). Built upon ‘network thinking’, very different strands of empirical analyses have been developed at multiple scales ranging from the global (Taylor and Derudder, 2016) to the national (Pan et al., 2017) and regional (Hall and Pain, 2006) scale. In this subsection, I introduce the theoretical underpinnings of urban network studies, their empirical agendas and the issue of geographical scales. Additionally, I also discuss two particular issues within urban network studies: the multiplexity of urban networks and urban polycentricity.

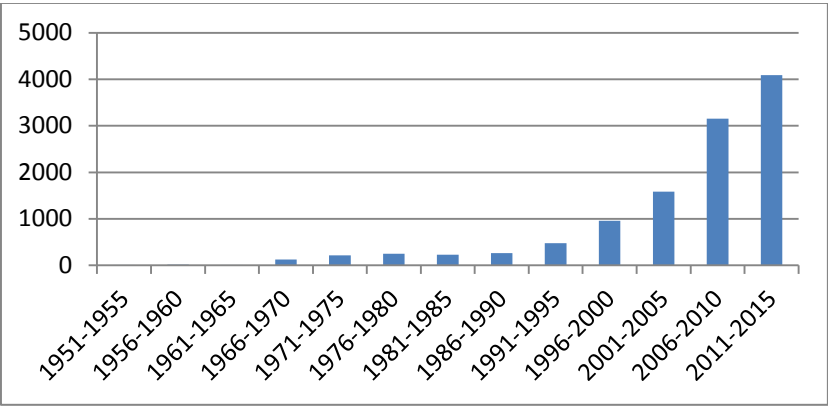


Figure 1.1. Evolution of publications dealing with ‘urban networks’ (drawn from Google Scholar, May 2017)

- Theoretical underpinnings

I briefly introduce a couple of key scholars' seminal work on understanding intercity connections to unpack the theoretical underpinnings of urban network studies. The first is Jane Jacobs' pioneering works on conceptualizing 'city economic growth' (1969; 1984). In her seminal theory of 'city economic growth', the idea of 'external relations of cities' was presented and, together with urban agglomeration effects, deemed to be a main element of economic growth. Although intercity relations were originally proposed in Jacobs' theoretical model¹, Saskia Sassen's 'global cities' (Sassen, 1991; Sassen, 2001) and Manuel Castells' (1996) 'space of flows' greatly influenced the adoption of 'network thinking' in urban studies. Sassen's research on global cities emphasises that 'vast multinational networks' (1991: 173) of advanced producer services firms enable global cities to relate to each other, and that the interactions among these global cities (e.g. London, New York and Tokyo) constitute an 'emerging transnational urban system' (2001: xvii). Sassen's pioneering work on understanding global city processes provides one of the theoretical building blocks upon which world city network research is premised (see the work of the Globalisation and World Cities (GaWC) research network; Taylor and Derudder, 2016). Manuel Castells is another key scholar, who proposed the new spatial logic of 'space of flows'. In his seminal book 'The Rise of the Network Society' (1996), networks are deemed to constitute the morphology of our societies in the 'informational age', and 'spaces of places' have been replaced by a new 'space of flows' (1996: 412). The 'space of flows' consists of three layers: the electronic impulses (1996) and infrastructure connections (1999) which provide the material support for the network society, the places (cities) which constitute the nodes and hubs of different networks, and the spatial organisation of managerial elites (expanded to people in a general sense) in terms of their activities such as work and movement. Although the logic of the 'space of flows' was devised to reformulate social studies for the global and information age, it can be envisaged as part of a wider meta-geographical shift towards understanding urban systems through the lens of 'intercity relations'. In this case, urban systems are viewed as a set of spatial relations between discrete and bounded cities. However, cities are not 'autonomous entities' that directly connect with each other, but rather 'agglomerations composed of many distinct networks – economic, social, political, technical or infrastructural' (Pflieger and Rozenblat, 2010: 2723). These distinct

networks, despite having different characteristics in terms of type, scale and structure, interconnect in cities and thus define cities' positionalities in networks. Meanwhile, the characteristics of urban spaces influence the formation of these networks (Pflieger and Rozenblat, 2010).

- Empirical agendas

'Network thinking' has been increasingly formulated in different disciplines that empirically examine 'urban systems' (e.g. Camagni and Salone, 1993; Rozenblat and Pumain, 2007; Neal, 2012; Pumain et al., 2015). From a geographical point of view, five main research lines stand out, including (i) mapping urban networks; (ii) describing network formations; (iii) tracking the changes of urban networks; (iv) modelling urban networks, and (v) discovering the formative mechanism underlying the formation of urban networks.

Mapping urban networks is the first step to understanding urban systems through the lens of relations. As mentioned before, individual cities are not directly connected to each other, but rather rely on a wider range of agents such as firms, people and flights. Mapping urban networks thus involves the operationalisation or projection of networks, that is, determining how these networks are produced. Couched in the terminology of social network analysis (SNA) literature, a city-to-city network is a one-mode network consisting of only one set of nodes, while a city-to-agent network, which is always the original specification of data collection in actual analyses (e.g. the presence of firms in cities), is a two-mode network consisting of two disjointed sets of nodes (i.e. cities and agents). It is possible to transform a two-mode network to a one-mode network by applying projection methods (Liu and Derudder, 2012). There are various methods of projection for different agents. For instance, the ownership structures of producer services and the volume of intercity transport provisions can be transferred as indicators of intercity connections (Zhao et al., 2017). Another example is the widely-used interlocking network model (INM), devised by Taylor (2001a) and widely applied by the GaWC, in which office networks of advanced producer service firms across cities are used to estimate intercity connections. Furthermore, after the production of network information on intercity connections, network graphing in an appealing form is another issue in

operational terms. One of the major obstacles to the visualisation of urban networks is that urban networks are always characterised by high densities, i.e. having closer connections between neighbouring geographical units (Tobler, 1970). Additionally, other obstacles include the absence of appropriate software and specialised layout algorithms for spatial networks. Nevertheless, the rapid development of visualisation techniques makes it possible to visualise the rich information contained in urban networks. Three state-of-the-art visualisation techniques seem to hold the most potential: (i) placing ‘arrows and bands’ on maps (Derudder et al., 2014); (ii) edge-bundling techniques (Holten and van Wijk, 2009; Selassie et al., 2011), and (iii) circular flow plots (Abel and Sander, 2014; Hennemann et al., 2015) (two notable exceptions to this are ‘corrgram’ and ‘OD map’; see, for instance, Wood et al., 2010; Bryant, 2011).

Describing network formations mainly deals with the calculation of the importance of cities and city-dyads and the formulation of the structures of urban networks. First, the importance of cities can be indicated through centrality analysis in a series of varied forms, including degree centrality (Ma and Timberlake, 2008; Alderson et al., 2010), betweenness centrality (Kräetke, 2014), eigenvector centrality (Smith and Timberlake, 2001), closeness centrality (Alderson and Beckfield, 2004) and flow centrality (Wall and van der Knaap, 2011). These varied forms of centrality reflect how the ‘importance’ of cities in a network may be defined (Sigler, 2013). For instance, betweenness centrality measures the number of shortest paths from all cities to all others through a certain city, thus assessing the importance of that city in brokering flows between two urban systems or two geographical scales. Second, the connectivities of city-dyads always take the form of the (valued) number of relations between two cities, which is arguably the simplest measure in urban network literature. Based on the geography of city-dyads, urban hinterworlds – a more meaningful concept describing cities’ relations with all other cities – have been developed to detect ‘urban influences’ (Taylor, 2001b). Third, studies on analysing urban structures involve a number of related objectives: (i) measuring the topological properties of urban networks, such as small-world characteristics (Schnettler, 2009), scale-free structures (Barabási and Albert, 1999) and power-law distribution (Zhao et al., 2015); (ii) partitioning urban systems based on the density

of intercity connections (Taylor et al., 2013; Zhang et al., 2017); (iii) comparing the structural equivalence of different urban networks (Choi et al., 2006; Ducruet et al., 2011), and assessing the polycentric structures at regional scales (one of the main objectives of the dissertation, which will be discussed in detail later on).

To track the changes in urban networks implies analysing the trajectories of the positionality of individual cities and city-dyads in networks over time, as well as to track how network structures have developed. As a result, this research stream can draw on research into describing network formations, but the aim is to move on to an analysis of the temporal dimension. Notable examples include examining changing patterns of transnational intercity connectivity (Derudder et al., 2010; see the special issue about examining changing patterns in urban systems in the journal 'Urban Studies'), historical evolution of transport (air, railway and maritime) networks (Wang et al., 2009; Ducruet and Notteboom, 2012), and the transition of urban systems at regional/national scales (Gordon and Richardson, 1996; Neal, 2011).

Modelling urban networks mainly relies on spatial and topological features-based approaches. First, and most commonly, urban networks can be reproduced by the simulation of a gravity model, in which the connectivities between two cities are assumed to be proportional to their 'sizes' and inversely proportional to the distance between them (Tobler, 1970; Enault, 2012). Gravity-based approaches are based on the premise of the independence of nodes. Most urban networks, however, are characterized by structural interdependence between cities: for instance, intercity connections between two cities tend to be strong if they share nearest neighbours (i.e. a transitive effect) (Dai et al., 2016). Recently developed topological models (e.g. exponential random graph models and actor-oriented stochastic models) have tackled this problem (Liu et al., 2013; Liu et al., 2015), while these topological models have their own limitations such as being confined to modelling binary edges (for details, see Dai et al., 2016). As a result, discovering combined spatial/topological models has recently attracted particular attention – a recent special issue of the journal 'Social Networks' on 'Integrating Social and Spatial Networks' is telling in this respect. Notable literature consist of Pumain et al.'s (2006) work, in which the diversity of level of nodes is expressed in the model of

Gibrat's Law, and Dai's (2016) work which attempts to incorporate spatial and topological factors in the generative network model (cf. Vértès et al., 2012). Nonetheless, urban research has made limited attempts to model urban networks by adopting the state-of-art techniques of network science.

Discovering the formative mechanisms underlying the formation of urban networks is closely related to the agenda of modelling urban networks, but focuses more on analysing their determinants. In the existing literature, various driving forces underlying the formations of urban networks have been discovered, which can be broadly divided into two types. The first type refers to those gravity-parameters that are deemed to directly affect the demands of intercity connections, including distance (Tobler, 1970) and the measures of city size such as GDP and population (Krings et al., 2009). Another type refers to homophily factors that could promote or restrain the strength of intercity connections, such as administrative borders (Ma, 2005), landform contiguity (Wu et al., 2017), cultural affinities (van Houtum and Lagendijk, 2001), economic alliances (Li and Wu, 2013) and political systems (Cartier, 2013).

Research on urban networks obviously does not focus on these aspects alone. For instance, a wide-ranging literature has emerged that explores the alleged economic implications associated with the networked development of urban systems (Capello, 2000; van Oort et al., 2010) and a range of governance issues at the regional scale. These empirical agendas are widely discussed across different geographic scales (intra-urban, inter-urban or regional, and national). However, it has been especially clear that academic debate on urban networks spans multiple scales, and that each scale has been associated with a particular scope of research. In the next sub-section, I briefly introduce the multi-scalar nature of urban network research.

- Multi-scalar nature of urban network research

Neal (2013) proposed a conceptual framework for the multi-scalar nature of urban network research, in which micro, meso, and macro scales are defined. Micro-urban network research focuses on the networks within individual cities, where roads, transit and telecommunication systems enable intra-urban commuting and communication, as well as the development of neighbourhood social networks. At

this scale, centres of employment and commercial activities are connected by these multiple networks. Commonly-used data sources include commuting data (Veneri, 2010), mobile phone positioning data (Kang et al., 2012) and taxi trajectory data (Goddard, 1970; Liu et al., 2012). These data, without exception, contain information on flows of people.

Meso-urban network research focuses on the intercity networks at regional and national scales. At these scales, intercity infrastructure like rail lines, highways, canals and telecommunication systems connect urban clusters of population and economic activity, while cities *per se* play the role of nodes in these networks. The literature on such meso-urban networks is exemplified by research on polycentric urban regions (PURs). PURs and urban networks at the regional scale are two intertwined concepts, with the former emphasising that different cities within a putative region have a 'relative balance' (Kloosterman and Musterd, 2001; Burger and Meijers, 2012). Multiplex linkages between cities, such as infrastructure connections, functional exchanges and corporeal movements, have been mapped at this scale, including corporate transaction links (Hanssens et al., 2014), knowledge exchanges (Li and Phelps, 2016a), transport infrastructure links (Liu et al., 2016), commuting flows (De Goei et al., 2010) and potential workflows within advanced producer service firms (Taylor et al., 2008).

Macro-urban network research focuses on inter-urban flows at the global scale and has two main representative schools: world city network (WCN) research, which focuses on the proxy of multinational corporations' knowledge flows across cities (see the work of GaWC; Taylor and Derudder, 2016), and global production network (GPN) research, which focuses on the networks forged by specific economic and political actors (cf. Coe et al., 2010). At this scale, intercity relations revolve around investment, trade and production among global gateways and hubs, drawing support from air lanes, maritime shipping lanes and Internet backbones (Witlox, 2011). Data sources for mapping global urban networks include information on networked location strategies of globalising business services firms (Taylor and Derudder, 2016), data on global airline routes (Smith and Timberlake, 2001), and data on global container shipping (Ducruet and Notteboom, 2012).

These scales are interconnected rather than isolated from one another. For instance, the YRD, which will be the empirical focus of this dissertation, is a regional organisation which is constituted by the gateway city of Shanghai and several other interconnected cities. When seen at the global scale, Shanghai can be understood as a main node in East Asia within the global urban network, with other cities constituting its hinterland and supporting its functions as a ‘global city’. Meanwhile, intra-urban organisations of each of the individual cities affect the way and positionality with which these cities are connected with other cities. Figure 1.2 describes the scaling interaction and scale-related remits in urban network research (adapted from Rodrigue et al., 2009; Witlox, 2011). In this dissertation, I focus on the meso-scale, i.e., urban networks within mega-city regions.

Scale	Nodes	Infrastructure links	Relations	Data sources
Macro (Global)	Gateways and hubs (airports and ports)	Air and maritime lanes, telecommunication systems	Investment, trade and production	Data on locational strategies of globalizing firms, data on airline routes, data on global container shipping
Meso (Regional/national)	Cities	Corridors (rail lines, highways, canals, telecommunication systems)	Urban systems and hinterland	Corporate transaction data, knowledge exchange data, transport data, commuting data, data on locational strategies of firms
Micro (Intra-urban)	Employment and commercial activities	Roads, transit and telecommunication systems	Commuting and communicating, social network	Commuting data, mobile phone positioning data, taxi trajectory data

Figure 1.2. Scaling interaction and scale-related remits in urban network research (adapted from Rodrigue et al., 2009; Witlox, 2011)

- Multiplexity of urban networks

The notion ‘urban networks’ is an abstract concept that can be represented in various forms of intercity connections. For instance, from the perspective of infrastructure connections, urban networks can take the forms of Internet backbones, airline networks, maritime networks and high-speed railway networks; from the perspective of social practices, urban networks can take the forms of business communications, knowledge exchanges and capital flows. Burger et al. (2014) conceptualise the presence of multiple linkages as the ‘multiplexity of urban networks’, in which three main arguments are developed. First, as different lenses correspond to different

agents that produce connections, different linkages do not necessarily have the same spatial structure and geographical scope. Second, cities in different networks do not necessarily play the same roles. Third, the multiplexity of an urban network is also related to the multi-scalar nature of urban networks, in that the change of a kind of functional linkage on a geographical scale will affect other functional linkages at other geographical scales. Burger et al.'s (2014) arguments offer a starting point for investigating the different network formations in a certain urban system.

Apart from taking different forms of intercity connections, the multiplexity of urban networks also relates to multi-layers of social interactions. Drawing on Castells' 'space of flows' (1996), urban networks can be envisaged as a combination of three layers of material support for social practices: the layer of 'technological infrastructure of information systems, telecommunications, and transportation lines' (Castells, 1999: 295) which determines and supports the network society, the layer of nodes and hubs that use the infrastructure to link wider localities in order to carry out these social processes, and the layer of the corporeal movements of people. The infrastructure layer provides a material basis for intercity connections and corresponding tangible flows, but does not cover the tangible flows as such. One obvious example is air traffic networks, in which the supply of route structures does not directly match the actual flows of passengers. The hub-and-spoke organisation of airline networks would result in overestimating the connectivity of 'major hubs' in the network of actual flows of passages (Neal, 2014). Similar observations can be made with respect to analyses of train networks (Zhang et al., 2016).

Combining the logic of multiple layers of urban networks and their functional multiplexity, intercity connections should above all be understood as a combination of different layered networks, with each layer taking multiple forms. On the one hand, these multiple networks have a different spatial organisation, while on the other hand, they are interdependent.

- Urban polycentricity

Polycentric development has been emerging as a widely used term in policy discourse and academic research, as well as a normative planning goal in Europe ('European Spatial Development Perspective', 1999). The core feature of

polycentric development is the decentralized accumulations of resources and flows. This new form of polycentricity has emerged as a response to recent processes of internationalisation and globalisation, technical changes in transport and information communication, demands of sustainability, and participatory decision-making in regional/urban governance. This is because polycentric development has been deemed to be related to higher social cohesion, environmental sustainability and economic competitiveness.

Urban polycentricity is a scale-dependent geographic phenomenon. A monocentric urban system at one geographic scale can be part of a polycentric urban system at another geographic scale. For instance, Southeast England is a monocentric region in which global economic and knowledge flows converge in London on the European scale, while these flows diffuse outwardly from Central London to surrounding cities such as Bournemouth, Swindon, Northampton and Peterborough, thus making the area a PUR at the regional scale (Hall and Pain, 2006). Despite this scale-dependence, the literature on urban polycentricity is often captured through the notion of 'PURs', which is the main focus in this research.

PURs are generally defined as having a relative balance in the importance of different cities (Kloosterman and Musterd, 2001; Burger and Meijers, 2012). The academic literature dealing with PURs covers a wide range of topics as diverse as exploring quantitative methods that assess polycentricity (Green, 2007; Limtanakool et al., 2009), assessing its alleged social economic and environmental effects (Meijers and Burger, 2010; Brezzi and Veneri, 2015), exploring its theoretical rationale (Kloosterman and Musterd, 2001; Lambregts, 2009), and discussing a range of governance issues (Hendriks, 2006; Xu, 2008). Furthermore, a series of planning frameworks have been devised to harvest the alleged benefits associated with PURs (Lee, 2007; Meijers, 2013). Representative examples include 'megaregions' envisioned in US planning circles, the EU's integrated spatial policy as set out in the Territorial Agenda 2020 (Commission of the European Communities, 2011), and mushrooming polycentric urban clusters in China (as studied in this research).

With regard to research on PURs, one specific conceptual clarification is required: namely, the distinction between morphological polycentricity and functional polycentricity, which are two substantially distinct approaches to understanding and measuring polycentricity (Burger and Meijers, 2012). The former centres on nodal features such as GDP and population (e.g. Spiekermann and Wegener, 2004; ESPON Monitoring Committee, 2007; Burgalassi, 2010), while the latter focuses on interaction, exchange and functional specialisation between cities (Burgalassi, 2010; De Goei et al., 2010). In other words, from a morphological perspective, a PUR could be simply defined as an urban region with a balanced distribution of city size; from a functional perspective, however, a PUR is more of an urban region with a balanced distribution of city functions and intercity interactions. For the same PURs, these two approaches could lead to similar or different measures, with potential causality between them (Derudder et al., 2017). Additionally, from the perspective of measuring methodology, the two approaches are not completely incommensurable. Burger and Meijers (2012) recently proposed a theoretical framework to link both approaches.

1.2.2 Emerging mega-city regions in China

- At a glance: the rise of China's mega-city regions

China has recently experienced rapid and unprecedented urbanisation and economic growth, especially since its reform started in 1978. However, its urbanisation and economic growth are not evenly spread across its territory; rather, this growth has been focused in coastal provinces and a handful of city-regions (Fan, 1997; Florida et al., 2008). The rapid urban growth within the YRD serves to illustrate: China's urbanisation rate has grown from less than 20% in 1978 to about 57% in 2016, while the urbanisation rate of the YRD mega-region has increased to 70% during that same period. These city-regions do not exist in the morphologically bundled form of single cities. Rather, increased economic integration and rapid developments in technologies of transportation and communication enable the dispersal of economic activities from individual geographically neighbouring cities to wider city regions, or the so-called sprawling 'urban galaxies' (Brenner and Schmid, 2012). With regard to the YRD, as Friedmann observes:

‘Adjacent periurban zones are gradually becoming fused, creating a continuous urban space that is served by high-speed trains and super-highways as well as by communication cables that integrate this vast urban space into an unprecedented habitat... (Friedmann, 2017: 58)’

Various terms have been coined to conceptualise these emerging regional organisations, including ‘megalopolis’ (Gottmann, 1964), ‘PURs’ (Kloosterman and Musterd, 2001), ‘global city-regions’ (Scott, 2001), ‘Zwischenstadt’ (Sieverts, 2003), ‘megapolitan areas’ (Lang and Dhavale, 2005) and ‘mega-city regions’ (Hall and Pain, 2006). These related concepts accentuate specific dynamics of the formation of these regions. For instance, the concept of the mega-city region stresses that mega-cities’ functions such as R&D and high technology have spread across a larger urban region. However, the concept of the global city-region, which expands the concept of global city described by Sassen (1991) into regional units, highlights the functional importance of global cities and their hinterland regions to national and global systems. Given that this research focuses on intra-regional intercity interconnections, I here adopt the concept of ‘mega-city region’ to name these emerging regional organisations in China.

Three leading examples of mega-city regions in China are the PRD, YRD and JJJ Clusters. Within these regions, commercial, business and administrative services (centred in Guangzhou, Shanghai and Beijing respectively) are linked to other urban centres and wider hinterlands across thousands of square kilometres. Leveraging the roles of gateway cities in connecting the global economy, these regions increasingly function as an integrated whole to support and address processes of global economic integration. This is especially the case in the new wave of globalisation, which has witnessed a ‘West-East shift’ in the global economy towards Asia (Frank, 2014). According to Pain (2008: 30), ‘the changing role of Chinese mega-city regions as ‘deepening points’ in the world economy to global mega-city regions, becomes of vital interest’. Against this background, the purpose of this research is to examine the networked formation of the YRD, one of China’s mega-city regions.

- What is driving the formation of Chinese mega-city regions?

The rise of Chinese mega-city regions seems to echo the ‘new city-regionalism’ in advanced capitalist economies (Scott, 1998; Ward and Jonas, 2004; Li and Wu, 2017): as globalisation proceeds, a ‘global mosaic of regional economies’ (Scott, 1998: 47) comes into being and begins to function as the spatial foundation of the global economy. The ‘new’ in ‘new city-regionalism’ implies the transition from territorially embedded politico-administrative regions to ‘relational and networked’ city-regions (Amin, 2004). As with the emergence of mega-city regions in the Europe and North America, the emerging mega-city regions in China also seem to be the outcome of a dual process that is interlinking wholesale economic globalisation and locational specialisation at the regional scale. On the one hand, the processes of globalisation have led to increased concentration of strategic control functions of advanced services in a limited number of large cities to ensure the smooth functioning of the global system. As a result, these large cities, which are often termed ‘world cities’ (Friedmann, 1986) or ‘global cities’ (Sassen, 1991), play a strategic role in the coordination and control of the global economy. On the other hand, as the ICT revolution and the development of knowledge-dependent forms of commercial production progress, the traditional concentration of advanced service activities in these large cities can disperse over wider cities and settlements to ensure access to the specialisation of economic activities, as well as ‘enjoy(ing) lower wages and rent and a better living environment’ (Yang and Yeh, 2013: 161). In the case of the YRD, Shanghai is home to core command-and-control functions, centre for advanced producer services and the gateway to the global airline network, while other service and manufacturing functions are scattered across a series of secondary centres (e.g. Nanjing, Hangzhou, and Suzhou) and other small cities in this region. For instance, Suzhou hosts large parts of the information technology industry and high-technology centres.

Apart from the simultaneous processes of globalisation and locational specialisation, discussing the emergence of city-regions in a Chinese context should not be separated from the context of historical idiosyncrasies and political intervention. First, specific historical contexts obviously matter when considering the path of generating mega-city regions. Zhang (2015) and Bei et al. (2015) recently investigated the historical paths of the PRD towards a global city region, in which

the revitalisation of the PRD as an integrated region can be deemed to be a continuation of its long-term trajectory. In Zhang's research, he introduced three main stages of industrialisation that shape regional formation. These include the colonial period, in which foreign capital was an important driving force of industrialisation, the communist centrally-planned period, with its emphasis on heavy industries, and the period of foreign investment-induced fast industrialisation, in which the accumulation and concentration of capital evidently came into being. However, individual cities within the PRD have different historical legacies, e.g. colonial heritage in Hong Kong, the diaspora of overseas investment, institutional arrangements in Shenzhen and the cultural legacy in Guangzhou, which also matter for the evolution of regional formations (Bie et al., 2015).

Second, the strong political undercurrents in China's economic system, which reflect the territorialisation of China's party-state (Cartier, 2015), have arguably been very important in shaping the regional formations of mega-city regions, especially with regard to intercity relations. On the one hand, the political hierarchies of cities (e.g. sub-provincial-level cities, prefectural-level cities and county-level cities) determine to a large extent their political and economic powers, as well as their connectivities in regional organisations. In other words, higher-level cities are entitled to greater fiscal and administrative power and enjoy preferential policies from the central and provincial governments, while these greater powers and policies in turn enable them to attract more flows of resources and people from other cities. By investigating the locational strategies of producer service firms in mainland China, these firms are evidenced to set up more regional headquarters in political centres rather than economic centres in the strict sense (for instance, producer service firms tend to set up their regional offices in Jinan instead of Qingdao in the Shandong province). On the other hand, political influence is also evident in the ingrained effect of administrative borders. Although China's regional governance has been witnessing the orchestration of city-regionalism (Li and Wu, 2017), its decentralisation policies induce 'entrepreneurial local states' to protect intra-regional economic activities and block the flow of resources, as well as restricting the free flow of migrant labourers by means of the household registration system (*hukou*). For instance, Shanghai implemented the well-known 173 project (i.e., building the special economic zone in

173 km² of the area of neighbouring Jiangsu) to block the transfer of FDI to the Jiangsu Province (Wei and Leung, 2005).

- Mega-city regions in China: A normative policy framework

The mega-city region concept is not only a scientific framework to help our understanding of urbanisation processes in China, but is also increasingly ‘translated’ into a normative policy framework. China has recently been pursuing the development of urban clusters (*Chengshiqun*) – a new spatial form of organisation of political and economic operations – to accommodate the country’s booming urban population and facilitate regional coordination and environmental sustainability. The definition of urban clusters, in general, resonates well with the connotation of mega-city regions: centred on a couple of large cities, multiple and more or less physically separate cities are functionally connected to each other. In the recently released national strategy on ‘new forms of urbanisation’, the notion of urban clusters was acknowledged as a key governance framework in China. As a result, numerous regional plans and urban clusters with official or semi-official endorsements have mushroomed. In the case of the YRD, its urban cluster development plan was recently approved by the State Council of China. For this plan, promoting intercity cooperation and building regional alliances is part and parcel of the plan goals.

- Is it different from similar places in Europe or North America?

The emerging mega-city regions in China can be seen as a new example of the resurgence of city-regions. It is clear that the development of Chinese mega-city regions manifests some different characteristics when compared with the European and North American perspective on city-regions. As Friedmann (2017) notes:

‘What is it about planning these (Asian) conurbations that is perhaps different from similar places in Europe or North America? Obviously, one difference is scale and density: Asian conurbations are multiples the size and density of city regions in the developed world. Another is the rapidity of their physical expansion. A third is their relative poverty compared to the West and the professional capacities of their bureaucracies. (Friedmann 2017: 59-60)’

Drawing on the literature on city-regions and Chinese cities, the main characteristics of Chinese city-regions are as follows:

- 1) Existing observations on archetypal PURs have mainly focused on (north-western) Europe, where the patterns of population and economic growth do not exclusively follow the patterns of large city logic (Dijkstra et al., 2013). However, Chinese urban clusters consist of larger cities and clearly inhabit a wider geographic scale. For instance, when the geographic delineation adopted in its Urban Cluster Development Plan is used, the YRD covers an area of 211,700 square kilometres, which is comparable to the size of the United Kingdom, and consists of 24 cities that each have a population of more than 1 million².
- 2) China's remarkable regional inequality – for instance, the enormous inequality in the provision of public services – has considerably hampered balanced development within urban clusters (Wei, 1999). The best example of this is the existence of an impoverished area around Beijing and Tianjin within the JJJ cluster. In this case, it is difficult to say that the region surrounding Beijing could undertake Beijing's non-capital functions and industrial transfer spillover.
- 3) From an economic perspective, the emergence of 'urban regions' is deemed a spatial outcome of post-industrial economic transitions in developed economies, in which inter-urban connections have been above all generated by advanced services. The formation of urban clusters in China, however, is tightly related to 'the performance of their manufacturing economies' (Pain and Hall, 2008: 1068).
- 4) Last but not least, and as discussed above, in the context of the reorganisation of administrative space in China (Ma, 2005), strong political undercurrents largely restrain the actual polycentric development of urban clusters. Meanwhile, the decentralisation and rescaling of state power in China leads to intense intercity competition (Wu, 2003). This is well evidenced by the fact that the effects of administrative borders in shaping socio-economic interactions have been stronger than in the West, where regions are more or less free to 'override purely political boundaries' and

regulatory supervision of national states in the context of capitalism's new post-Fordist economic form and the emerging 'new regionalism' (Harrison, 2013). In other words, 'the effects of territorial boundaries on the flows of local and non-local forces are not absolute as the boundaries are generally porous' (Ma, 2005, p. 484).

As a result, the novelty created by emerging cities (and city-regions) in China needs to be investigated in a more critical way (Wu, 2016). Against this backdrop, this research attempts to engage the analytical frameworks of urban networks in the Chinese case, with a particular emphasis on these characteristics of Chinese city-regions.

1.3 Research questions

As illustrated in the background section, while the approach of urban network research paves the way to understanding urban/regional systems in the era of globalisation and informationalisation, investigations into the regional formation within the emerging mega-city regions in China are still rather thin on the ground. Some notable exceptions that recently document the rise of Chinese city regions by referring to the qualitative and quantitative framework of urban network studies include Zhang (with Kloosterman, 2016; 2017), Li and Phelps (2016a; 2016b), Liu et al. (2016) and Zhao et al. (2017).

To bridge the gap between state-of-the-art urban network research and our limited understanding of the intra-regional formation of Chinese mega-city regions, this dissertation offers an in-depth analysis drawing on the case of the YRD. Given the multiplexity of urban networks, I map three kinds of intercity connections, i.e. transport infrastructure links, business interactions and intercity mobility flows. Based on a range of analyses of the three networks, I will address three major research questions:

- 1) What are the spatial patterns of intercity connections within the YRD from the lens of multiple linkages?

Describing the spatial patterns of urban networks is the first step in understanding the regional formations they produce. The first objective will be to systematically survey the spatial patterns of the multiplex networks. This will start with measuring cities' and city-dyads' connectivities and extend into the investigation of network structures. Chapters 2 and 3 map the urban networks of infrastructure links and intercity mobility, while Chapter 4 presents patterns of business interactions. Chapter 5 compares these multiplex networks.

2) Is the YRD a polycentric urban region?

Polycentric development has been deemed to be one of the core features of spatial patterns in the YRD (Hall and Pain, 2006). This region's polycentricity has also been repeatedly verified in the literature (Song, 2014; Li and Phelps, 2016a; Li and Phelps, 2016b; Liu et al., 2016). In this research, I re-assess the YRD's polycentric structure, but extend existing research through two particular sets of analyses (1) differentiating the polycentricity of transport infrastructure provision and actual passenger flows and (2) exploring the sensitivity of selecting cities when measuring polycentric structures. Chapter 2 first investigates the biases when using infrastructure networks to assess the (polycentric) formation of actual intercity flows, with a related and extra theme on presenting an alternative approach for approximating actual flows in physical infrastructure networks. Chapter 3 formally re-explores the polycentric nature of the YRD. Subsequently, Chapter 4 focuses on the issue of selecting cities when assessing polycentricity.

3) What are the explanatory factors behind these spatial patterns?

To understand why patterns of intercity connections manifest themselves in the way they do, I devise two parallel avenues of research. First, I try to directly analyse the determinants of the multiplex urban networks. Chapter 5 goes directly to the heart of this question, exploring whether a series of potential factors such as distance, GDP, population and political levels affect each network differently. Second, I attempt to re-delineate the YRD based on the pattern of intercity connections, and then explore the processes underlying the regional (re-)production (Chapter 6). The second avenue of research approaches the problem indirectly by comparing an intercity

interactions-based regionalisation with a regionalisation based on a series of economic, cultural, environmental and political attributes.

1.4 Case study region and data

1.4.1 Case study region: the Yangtze River Delta (YRD)

The YRD region is situated at the intersection of the Yangtze River and the coast. It has various boundaries, which are continually changing, both in official documents and in the academic literature. With the exception of Chapter 4, I adopt the largest scope possible (including Shanghai Municipality, Jiangsu Province, Zhejiang Province and Anhui Province) throughout this research. Given that Chapter 4 deals with the issue of selecting cities when assessing polycentricity, I adopt a small scope for this chapter, which is consistent with the delineation adopted in the YRD Urban Agglomeration Development Plan, in order to avoid the pre-hoc determinism of selecting more cities in this chapter than strictly required (Figure 1.3).

After the Chinese economic reform program of 1978, Shanghai and a series of other main cities within the YRD (such as Nanjing, Suzhou and Hangzhou) experienced tremendous economic growth. This region is increasingly becoming the most important economic centre in mainland China. According to the broad scope mainly adopted in this research, the YRD covers 3.6 % of the nation's total land area and is home to 16.6% of the population, but generated 23.5% of the national GDP, 23.9% of the national fiscal revenue, and received 41% of China's inward foreign investment in 2014.

The YRD is a putative PUR, at least from a morphological perspective. It consists of five political centres, which include one municipality, three sub-provincial cities (Nanjing, Hangzhou and Ningbo) and three provincial capitals (Nanjing, Hangzhou and Hefei) (for additional detail on China's administrative divisions, see Ma, 2005), six economic centres with a GDP of over 800 billion RMB (i.e. Shanghai, Suzhou, Hangzhou, Nanjing, Wuxi and Ningbo), and six demographic cores with a resident population of over eight million (Shanghai, Suzhou, Wenzhou, Hangzhou, Xuzhou and Nanjing)³. These cities and other small cities are closely connected through intensive motorway and (high-speed) railway networks. The development of high-

speed railway (HSR) networks within this region offers an excellent example of the intensive nature of the intercity connections: 16 HSR lines are in service, while four more are in the construction and planning phases within the YRD. Moreover, 33 prefecture-level or above cities – 80% of all 41 cities within the YRD – have been connected into HSR networks (according to the data in 2016).

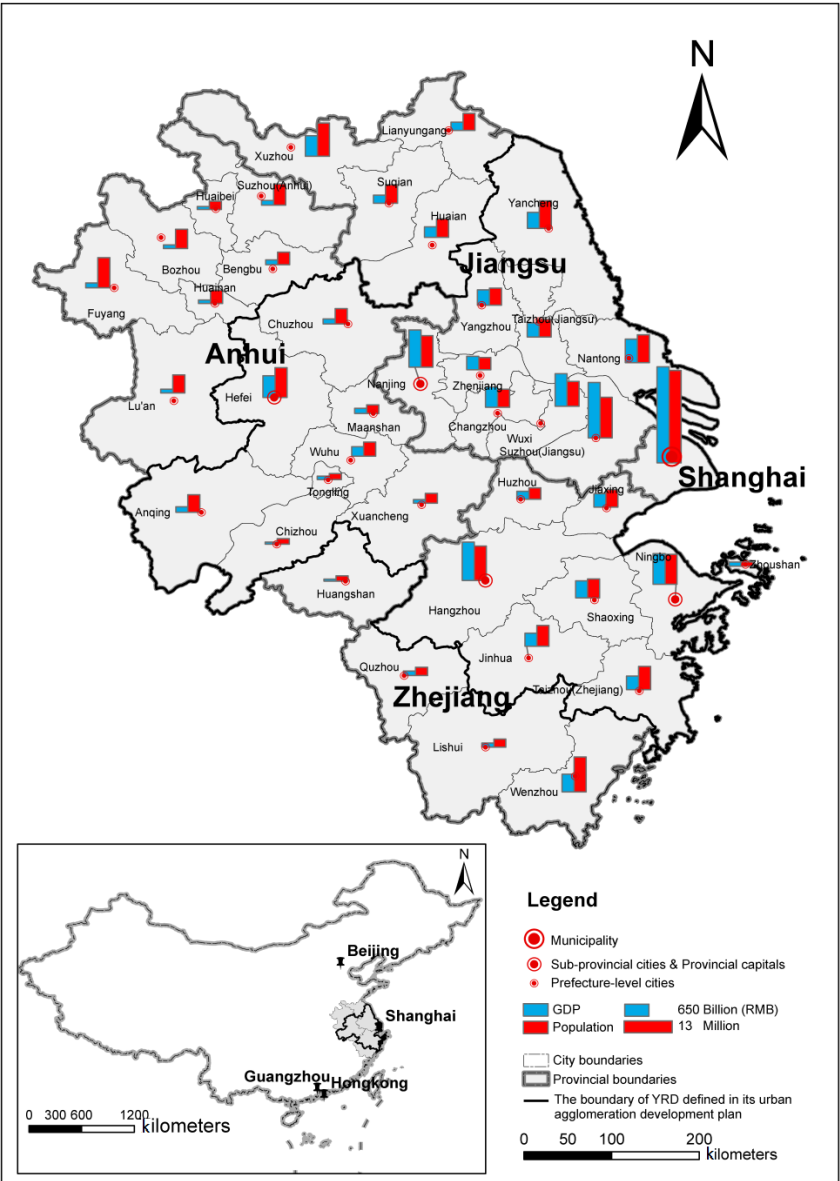


Figure 1.3. The Yangtze River Delta with its GDP and demographic distribution

1.4.2 Data

This research starts by mapping the multiplex urban networks within the YRD. Different types of relational data will be used, including data on intercity transport linkages, intercity mobility, and business flows.

- Data on intercity transport linkages

Two datasets have been created to map intercity transport linkages: the records of the operations of intercity HSR and composite data on intercity integrated transport linkages. The first dataset on operational train scheduling was gathered from the national train ticketing website (www.12306.cn), in which each record offers information on prices, transit stations and dwell time. The data were collected over one fixed day in order to avoid the possible effects of operational fluctuations. Chapter 2 uses this dataset.

The composite dataset on intercity integrated transport linkages includes bus and rail provisions, in which the number of daily direct trains and buses between two cities are used as main indicators. The information was crawled from online bus and train schedule search engines (such as <http://www.piaojia.cn>; <http://www.12306.cn>) in January 2017. The bus data were cross-referenced with other databases, such as www.checi.cn. This dataset is used in Chapter 5.

- Data on intercity mobility

Data on intercity mobility was derived from geo-tagged posts on Weibo (one of China's main online social networking and microblogging services). Weibo's geo-tagged posts offer information on where and when users posted their messages, and thus have the potential to reflect intercity mobility. I used the public application programming interface (API) to gather the geo-tagged records submitted within the YRD. I first gathered the geo-tagged records submitted between September 2013 and April 2014, which contained 27.53 million records, to carry out the research in Chapter 3. After harvesting more records in 2015, I used 53.52 million records submitted between January 2014 and November 2014 to carry out the research in Chapter 6. In Chapter 3, I use a directed star topology to connect the place of users'

registration and their geo-tagged locations as a proxy for intercity mobility, while Chapter 6 connected successive geo-tagged records over a period of 48 hours as a proxy for users' trajectories (for more operational details, see the corresponding chapters). Additionally, the potential and representativeness of Weibo data for analysing geographical patterns has been verified in both chapters.

- Data on business flows

The intercity business flows are projected using a Chinese firm-city database by implementing the INM model devised by the GaWC research group (Taylor, 2001a). Chapters 4 and 5 discuss the operationalisation of constructing the business network from the firm-city database in detail. Here I restrict myself to the data source.

The database includes the information of locational strategies of 247 main service firms in China. Based on sectoral ranking for 2013, I first selected 50 accounting firms (source: goo.gl/TDDy9p), 50 advertising firms (source: goo.gl/37FERZ), 50 management consultancy firms (source: goo.gl/v43XI5), 35 law firms (source: goo.gl/OsCspB), 21 main nationwide banks (source: goo.gl/fwHRMr), 30 insurance firms (source: goo.gl/2z7oW9), 30 security firms (source: goo.gl/gcFhg8), and 30 trust firms (source: goo.gl/Pvn2Zh) in mainland China. I crawled the locational information on their firms' branches in all 289 cities at prefecture level and above in mainland China to encode the two-mode firm-city database (for more details, see Chapter 4). As some of these firms did not offer related information on their locational strategies during the data collection, the actual list of firms only includes 247 firms: 50 accountancy firms, 41 advertising firms, 23 management consultancy firms, 35 law firms, 21 bank firms, 26 insurance firms, 30 security firms and 21 trust firms.

1.5 Organisation of this dissertation

The remainder of this dissertation is organised as follows. Figure 1.4 shows an overview of the formative chapters (chapters 2 to 6) of this dissertation, in which the horizontal axis represents the three kinds of intercity linkages and the vertical axis represents the three research questions. Each block of this diagram shows which chapters examine which questions based on which kinds of network data.

<u>Question 3</u> Explanatory factors	<u>Chapter 6</u> (Regionalisation from the perspective of intercity mobility)		
	<u>Chapter 5</u> (An analysis of the determinants of multiplex urban networks)		
<u>Question 2</u> Polycentricity	<u>Chapter 2</u> (Approximating actual flows in physical infrastructure networks)	<u>Chapter 3</u> (Using location-based social media to chart the patterns of people moving)	<u>Chapter 4</u> (Sensitivity of polycentricity to the choice of ‘centres’)
<u>Question 1</u> Spatial patterns	<u>Chapter 5</u> (An analysis of the determinants of multiplex urban networks)		
	Transport infrastructure links	Intercity mobility	Business interactions

Figure 1.4. Overview scheme of the formative chapters (chapters 2 to 6) of this dissertation

Chapter 2 maps the HSR network and its passenger flows within the YRD, with a particular focus on differentiating physical infrastructure provisions and actual passenger flows these infrastructure connections undergird. To be specific, I review common biases when using infrastructure networks to approximate actual intercity flows and present a method to improve our estimation of urban interaction in and through infrastructure networks by focusing on the example of passenger railways.

Chapter 3 maps the intercity connections within the YRD based on three million individuals’ space-time footprints derived from Weibo. I examine the spatial patterns of this intercity connection in general and investigate the influences of administrative boundaries and cities’ administrative level in particular. Furthermore, I benchmark our findings through re-examining the widely-documented pattern of the polycentric developments in the YRD.

Chapter 4 investigates the polycentric structure of the YRD from the lens of intercity business linkages, but with a particular focus on the sensitivity of selecting cities when accessing polycentricity. Based on a Chinese firm-city data source, this chapter investigates the influence of the choice of the number of cities in the quantified polycentricity. Furthermore, I discuss which cities are deemed to actually contribute to the polycentricity of the YRD.

Chapter 5 examines different determinants of the three types of urban networks within the Yangtze River Delta. Based on the analysis of network correlation and network regression, the relations between the three urban networks and a series of potential factors such as distance, GDP, population, administrative borders, landform contiguity, cultural affinities, economic alliances and political levels are investigated. The results show the reasons for the different structures of the three types of urban networks.

Chapter 6 applies a community detection algorithm to the YRD's daily intercity mobility network to produce an interaction-based regionalisation, and then explores the processes underlying this regional (re-)production by comparing it with attribute-based regionalisation. This chapter examines the influences of overlapping physical, economic, cultural, and administrative spaces on regional integration.

Finally, Chapter 7 summarises the main findings of this research through providing answers to the three main research questions. It also outlines the policy implications of the present study and proposes some avenues for further research.

The five formative chapters – with the exception of the Chapter 4 – are co-authored papers where I am the first author. For these chapters, I conducted the research design, data collection, statistical analysis, and manuscript preparation. My co-authors' work contributes to better framing the research and/or helping out with concrete technical questions. The first, fourth and final chapters of this dissertation were devised and written by myself alone.

Notes

1. It should be noted that ‘intercity relations’ in Jacobs’s theoretical model focus more on cities’ complementarities, rather than referring to ‘urban networks’ in a general sense.
2. The demographic data adopted in this research is defined based on the numbers of permanent population, i.e., demographic data including population without local *hukou*, unless otherwise specified.
3. The statistical data was obtained from the Statistical Yearbook for the provinces of Jiangsu, Anhui and Zhejiang and the municipality of Shanghai in 2016. The data on population and GDP was collected at the scale of municipal units that consist of urban districts and extensive counties.

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2. Approximating actual flows in physical infrastructure networks: The case of the Yangtze River Delta high-speed railway network

Zhang W, Derudder B, Wang J and Witlox F. (2016) Approximating actual flows in physical infrastructure networks: The case of the Yangtze River Delta high-speed railway network. *Bulletin of Geography. Socio-economic Series* 31: 145-160.

Abstract

Previous empirical research on urban networks has used data on infrastructure networks to guesstimate actual intercity flows. However, with the exception of recent research on airline networks in the context of the world city literature, relatively limited attention has been paid to the degree to which the outline of these infrastructure networks reflects the actual flows they undergird. This study presents a method to improve our estimation of urban interaction in and through infrastructure networks by focusing on the example of passenger railways, which is arguably a key potential data source in research on urban networks in metropolitan regions. We first review common biases when using infrastructure networks to approximate actual intercity flows, after which we present an alternative approach that draws on research on operational train scheduling. This research has shown that ‘dwell time’ at train stations reflects the length of the alighting and boarding process, and we use this insight to estimate actual interaction through the application of a bimodal network projection function. We apply our method to the high-speed railway (HSR) network within the Yangtze River Delta (YRD) region, discuss the difference between our modelled network and the original network, and evaluate its validity through a systemic comparison with a benchmark dataset of actual passenger flows.

2.1 Introduction

In his groundbreaking book on ‘the rise of the network society’, Castells (1996: 377) examines the new spatial logic emerging from the ‘complexity of the interaction between technology, society, and space’. This new spatial logic, which Castells famously terms ‘the space of flows’, has three layers: the electronic impulses in networks, the places which constitute the nodes and hubs of the different networks, and the spatial organisation of people in terms of their work, play, and movement. The first layer provides the material support for the network society, i.e. it is the ‘technological infrastructure of information systems, telecommunications and transportation lines’ (1999: 295) that reflects, determines, supports, and/or enables the network society. Although Castells’ book focuses on the information age and the electronic time-sharing practices through space this has brought about, his research can be envisaged as part of a wider metageographical shift emphasizing the importance of ‘networks’ in the organisation of space. For instance, in urban geography we have seen a shift towards ‘urban networks’ as a major analytical lens which can understand ‘urban systems’ (e.g. Camagni and Salone, 1993; Meijers, 2007; Zhao et al., 2014).

Based on this general premise, we have seen the emergence of a rich empirical literature on the position of cities in networks at different scales, ranging from ‘world city networks’ at the global scale (e.g. Taylor and Derudder, 2015) to urban networks that constitute polycentric metropolitan regions (e.g. Burger et al., 2014). The former literature highlights – in spite of its rich diversity – the role of major cities at the crossroads of multiple networks. For instance, when cast in terms of Castells’ three-layered structure, the airline networks studied by Smith and Timberlake (2001) and Zook and Brunn (2006) can be understood as analyses of a key infrastructural network (the first layer) centered on world cities (the second layer) in order to facilitate the movement of capital, people, and information (the third layer). Similar observations can be made with respect to analyses of Internet backbone networks (Rutherford et al., 2004; Tranos, 2011), logistics networks (O’Connor, 2010; Ducruet and Notteboom, 2012), office networks of firms (Rozenblat, 2010; Derudder et al., 2013), or a combination of infrastructures (Devriendt et al., 2010; Ducruet et al., 2011).

In strict terms, infrastructure can be thought of as the basic physical and organisational structures and facilities (e.g. ports, buildings, roads, power supplies) needed for the operation of individual organisations and enterprises and/or society and the economy at large. However, infrastructure networks merely provide a material *basis* for tangible flows; they do not cover these tangible flows as such. A good example would be the analysis of urban networks through the lens of air traffic networks (Derudder and Witlox, 2005; Neal, 2014): although data on air traffic networks are widely used in urban network research (Smith and Timberlake, 2001; Matsumoto, 2004), in most cases data tend to cover the *supply* of route structures between airports (e.g. the data from International Civil Aviation Organisation (ICAO) and International Air Transport Association (IATA)). This focus on the supply side of infrastructure networks does to some degree reflect demand for connectivity between city-pairs, especially in an increasingly deregulated air travel market, but there are of course major intervening effects. The most important one relates to the hub-and-spoke organisation of global airline networks, where many passengers are routed via major airports to their destination. This overvaluing of ‘major hubs’ reveals that an analysis of supply of infrastructure provision does not directly match the actual demand or use. Neal (2014) has recently demonstrated the effect of this for urban network analysis, and this prompted him to reveal the structural uniqueness of the networks of supply and demand.

To date, however, few studies of urban networks have analysed the parallels and differences between physical infrastructure networks and the actual flows they enable. In most cases, the former is used as a proxy for the conceptually more meaningful latter. This implies that, in spite of a plethora of papers analysing urban networks through the lens of infrastructure networks, there remains scope for analytical improvement. There are some comparative studies on different layers of urban networks that may inform our understanding of their spatial outline (e.g. Choi et al., 2006; Taylor et al., 2007; Liu et al., 2012), but in this paper we focus more specifically on how data on infrastructure provision can be adapted so that it better reflects actual intercity flows. To this end, we focus on the example of rail networks reflecting urban network-formation at the level of ‘megaregions’ (cf. Harrison and Hoyler, 2015). Previous research on this topic serves to clarify our research question.

In a recent analysis of infrastructure networks in South Asia, Derudder et al. (2014) find that cities along transport corridors, often defined by road and train networks, are well connected. However, this may be an artifact of the network lay-out rather than ‘real connectivity’: the connectivity of cities located on a connection between two major interacting nodes may be vastly over-estimated. In the case of the Yangtze River Delta, which will be the empirical focus of this paper, this would result in overestimating the connectivity of Wuxi as it is on the Nanjing-Shanghai HSR line (which is officially called *Hu-Ning* Intercity Line), granting the Wuxi-Nanjing and Wuxi-Shanghai links de facto equal status to the Shanghai-Nanjing connection (Figure 2.1). The purpose of this paper is to elaborate a method that would allow for an improved guesstimate of intercity flows based on infrastructures. The paper focuses on urban networks at lower scales such those in mega-city-regions and countries, where road and rail networks are the key facilitators of intercity flows.

The remainder of this paper is organized as follows. First, we give a brief overview of the methods for measuring intercity interactions in railway networks in previous research, and survey the deficiencies encountered by the proxies of infrastructure networks for actual intercity interactions in more detail. Following this discussion, we focus on setting out an alternative approach to approximating passenger flows in railway networks. This is followed by an empirical test of this approach by applying it to the HSR network within the Yangtze River Delta (YRD) and examining the difference between our transformed network and the original network. We then evaluate the validity of our method through a comparison with a benchmark dataset of actual flows of people, after which the paper is concluded with an overview of our main findings and a discussion of possible avenues for further research.

2.2 Methods for measuring intercity interactions through railway networks

Railways constitute one of the main means for transporting people between cities, and thus play a major role in the structuring of intercity interactions, especially at the regional and national level. Within the burgeoning literature on intercity networks and spatial interactions, many researchers have thus tried to measure intercity linkages through the lens of railway networks (e.g. Hall et al., 2006; Luo et al.,

2011). However, few papers have mapped intercity interactions using a *direct* measure of the volumes of intercity passenger flows. This can be attributed to the lack of data on actual traffic volumes between train stations. As a consequence, a number of researchers have resorted to proxy strategies for measuring intercity linkages. Two main solutions have been devised in the context of railway networks: (1) measuring the potential for interactions by train, and (2) measuring the volume of trains making intercity connections.



Figure 2.1. The high-speed railway network within the Yangtze River Delta

2.2.1 Interaction potential

Interaction potential can be defined as the convenience and opportunity of intercity travel through rail transport. The most commonly used indicator in this respect is travel time, which is often seen as an ‘unproductive’ cost (time) (Lyons et al., 2007) in a journey influencing potential intercity interaction (see for example, Bruinsma and Rietveld, 1993; Murayama, 1994; Kramar and Kadi, 2013). Similarly, travel distance or the generalized cost of transport (distance and time) can also be used as an indicator of measuring the possibility of intercity journeys (see for example, Spence and Linneker, 1994; Wang et al., 2009). A major obstacle to using this proxy of interaction potential is that infrastructures merely enable the ‘potential’ of intercity interactions; actual passenger volumes are co-determined by the ‘demand’ for intercity interactions and this ‘supply’ of transport infrastructures. The ‘demand’ for intercity travel can be attributed to the socio-economic attributes of cities and the distance between cities (Davies, 1979; Krings et al., 2009). Even having convenient and efficient transport infrastructures linking to each other does not guarantee that two (social or economic) proximate cities will also exchange a lot of passengers.

A related approach for assessing the potential is using a range of combined measures that not only reflect the quality of infrastructure networks, but also the demand for intercity linkages. For instance, the indicator of weighted travel time suggested by Gutiérrez (1996; 2001) consists of travel times and urban mass which refers to, for example, gross domestic product or population. However, the ‘demand’ for intercity linkages is using simulation approaches rather than more direct measures. Taken together, these indices expressing the potential of intercity interaction by train mirror the quality or efficiency of train transport infrastructures itself.

2.2.2 A proxy based on infrastructure volumes

The number of daily or weekly trains has been used as a proxy (Hall et al., 2006; Derudder et al., 2014). Using this proxy instead of the measurements outlined in the previous section has two advantages. As the volume of carriages contains more *direct* information of intercity flows, it seems to be a more suitable measure of passenger flows. In addition, the information on train numbers can be collected via open information platforms of transport companies much easier than through other

ways such as surveys. This proxy also can be viewed as the assessment of transport infrastructures per se, which indicates the traffic supply of infrastructure networks at the level of carriages.

Using the volume of carriages assumes that every train holds similar passenger volumes, which is of course is problematic. More importantly, this proxy also assumes that the number of trains is proportional to the volume of intercity passengers between any pair of cities. This is problematic assumption because operationally, train networks are organized by chain structures, unlike air travel or bus trips where direct non-stop services are main organisational forms. A link from an origin to a destination produces $n(n-1)/2$ links between any pair of stations if there are n stations en route. In this case, the most important cities hold similar positions with smaller cities that can be found on the same railway line, although this obviously does not conform to the actual distribution of intercity flows of passengers. As a corollary, the volumes of passengers of 'major cities' tend to be underestimated, while the roles of 'small cities' located on major traffic arteries tend to be overstated. Consequently, this proxy structurally predetermines a flatter structure in the urban hierarchy than warranted.

2.3 An alternative approach to approximating passenger flows in railway networks

2.3.1 Dwell time

Dwell time, the time a train remains in a given station, is primarily determined by the number of boarding and alighting passengers, as well as some extra factors such as passenger behaviour, platform and vehicle characteristics, and dispatching rules (Lin and Wilson, 1992; Wiggendaad, 2001; Jong and Chang, 2011). It is a key parameter of the performance of train operations as insufficient dwell time would lead to train delays, while excessive dwell time would result in inefficient operations (Jong and Chang, 2011). Dwell time, therefore, is set by scientific and efficient principles, which mainly follow the experience of the length of alighting and boarding processes from the past. A normal dwell time lasts between 2 and 5 minutes, with a dwell time of over 5 minutes often implying extraordinary dispatching such as coupling, decoupling, and meeting occurs in that station.

These underlying principles suggest that there is a potential for modelling passenger flows based on the corresponding dwell time in a certain station. However, eliminating the influence of extraordinary dispatching rules on dwell time is needed: special dispatching (e.g. overtaking, meeting, insufficient headway) clearly biases the interpretation of dwell times, and thus represent outliers. In our research, we will adopt the strategy of replacing outliers with mean values. This is mainly based upon two considerations: (i) simply deleting outliers would be equal to suggesting that trains did not stop in these stations, which is obviously unreasonable; and (ii) as the cause of producing outliers is known in our case, it is possible to replace these outliers using reasonable values to eliminate the effect of abnormal dispatching.

After dealing with outliers, the adjusted dwell times thus correspond with the time of boarding and alighting. According to Jong and Chang's research (2011), the linear relation between the time of passenger flows and the volume of passenger flows is statistically significant. We thus introduce a dummy parameter ' r ', which refers to the correlation coefficient between passenger volumes and the boarding and alighting time, to simulate the volume of passenger flows. That is, the volume of passenger flows ' v ' is dependent on its adjusted dwell time ' t ', so that:

$$v = t \times r \quad (1)$$

The stations of origin and destination do not have dwell times, albeit that they are often the main sources of passengers. To this end, we impose an assigned value by setting a relatively reliable boarding and alighting time in starting and terminal stations for empirical regions. In our case, the HSR network within the Yangtze River Delta region, most maximal dwell times (after replacing outliers) are around 5 minutes. We posit that the passenger volume from original or to terminal station resemble (or slightly exceed) the passenger volume in the largest transit station as a general rule. Thus, we assign the dummy dwell time as 3 minutes.

2.3.2 Approximating passenger flows between city-pairs

As our object of research is cities rather than train stations, we combine multiple stations into one city through summing adjusted dwell times in the case of there being multiple stations in a single city. From an operational perspective, the

distribution of passenger flows for a given train that passes ‘ n ’ cities can be summarized by means of an upper triangular matrix as shown in Table 2.1, where ‘ v_{ij} ’ is the number of passengers boarding in city ‘ i ’ and alighting in city ‘ j ’. In Table 2.1, each row indicates the distribution of alighting for passengers boarding in city ‘ i ’; each column indicates the distribution of boarding for passengers alighting in city ‘ j ’. As a consequence, the sum of each row (V_{ix}) is the number of boarding passengers in city ‘ i ’, and the sum of each column (V_{xj}) is the number of alighting passengers in city ‘ j ’.

Following equation (1), passenger volumes in city ‘ i ’ and ‘ j ’ can be obtained by:

$$v_{ix} + v_{xi} = v_i = t_i \times r \quad (2)$$

$$v_{jx} + v_{xj} = v_j = t_j \times r \quad (3)$$

If we hypothesise that in the course of a day the boarding and alighting passengers are equivalent in any of the transit cities, then can be formulated as¹:

$$v_{ix} = v_{xi} = v_i / 2 \quad (4)$$

$$v_{jx} = v_{xj} = v_j / 2 \quad (5)$$

Table 2.1. The distribution of passenger flows for a certain train

Alighting city Boarding city	City ₁	City ₂	...	City _j	...	City _(n-1)	City _n
City ₁	0	$v_{1,2}$	...	$v_{1,j}$	...	$v_{1,n-1}$	$v_{1,n}$
City ₂	0	0	...	$v_{2,j}$	...	$v_{2,n-1}$	$v_{2,n}$
...
City _i	0	0	...	$v_{i,j}$	...	$v_{i,n-1}$	$v_{i,n}$
...
City _(n-1)	0	0	...	0	...	0	$v_{n-1,n}$
City _n	0	0	...	0	...	0	0

To evaluate the number of passengers boarding at city ‘ i ’ and alighting at city ‘ j ’ (i.e. v_{ij} in Table 2.1), we first survey the probability of boarding in city ‘ i ’ and alighting in city ‘ j ’ for all passengers. For any passenger in the passenger distribution ‘ V ’, we believe that boarding in city ‘ i ’ and alighting in city ‘ j ’ are two mutual independent events. According to the rule of the probability of two mutual independent events happening together, the probability of boarding in city ‘ i ’ and alighting in city ‘ j ’ can

be obtained by multiplying the probability of boarding in city ‘*i*’ by the probability of alighting in city ‘*j*’. As a corollary, we can approximate the number of passengers boarding at city ‘*i*’ and alighting at city ‘*j*’ (v_{ij}) from multiplying the number of boarding passengers at city ‘*i*’ (v_{ix}) by the number of alighting passengers at city ‘*j*’ (v_{xj}):

$$v_{ij} = \alpha \times v_{ix} \times v_{xj} \quad (6)$$

where α is a dummy parameter describing the relation between v_{ij} and the product of v_{ix} and v_{xj} .

Combining the different equations, v_{ij} can be expressed as the function of dwell times:

$$v_{ij} = \alpha \times r^2 \times (t_i \times t_j) / 4 \quad (7)$$

However, for the cities of origin or destination, the number of boarding or alighting passengers (v_{ox} or v_{xd}) is equal to the total passenger volumes (v). In these cases, the number of passengers of boarding in origin city ‘*o*’ and alighting in transit city ‘*i*’ (or boarding in transit city ‘*i*’ and alighting in destination city ‘*d*’) is given by:

$$v_{oi} = \alpha \times r^2 \times (t_o \times t_i) / 2 \quad (8)$$

$$v_{id} = \alpha \times r^2 \times (t_i \times t_d) / 2 \quad (9)$$

Similarly, the number of passengers of boarding in origin city ‘*o*’ and alighting in destination city ‘*d*’ is given by:

$$v_{od} = \alpha \times r^2 \times (t_o \times t_d) \quad (10)$$

Based on equations (7-10), the volume of intercity passengers can be obtained in the form of multiples of ‘ $\alpha \times r^2$ ’. In the next section, we operationalise this approach by means of a case study.

2.4 Approximating the flows of high-speed railway (HSR) passengers within the Yangtze River Delta

2.4.1 Case region, data and transformed network

High-speed railway (HSR) travel plays an important role in facilitating individual movements, thus enabling the formation of larger labour markets in regions and fostering wholesale regional integration (Blum et al., 1997; Chen, 2012; Zheng and Kahn, 2013). Since the first HSR² in China became operational in 2007, China's HSR network has been growing rapidly. By the end of 2013, its length reached 10463 km, constituting the longest HSR network in the world. The Yangtze River Delta region is one of the main mega-city regions with intensive HSR networks, where 22 major cities – 54% of the entire 41 cities within the YRD³ (i.e., Shanghai, Nanjing, Hangzhou, Suzhou (Jiangsu), Hefei, Changzhou, Wuxi, Zhenjiang, Bengbu, Chuzhou, Huainan, Lu'an, Quzhou, Suzhou (Anhui), Xuzhou, Jinhua, Ningbo, Huzhou, Shaoxing, Taizhou (Zhejiang), Wenzhou, and Jiaxing) – are interconnected through HSR (Figure 2.1). Our empirical analysis focuses on the passenger flows of HSR among these 22 cities.

Data were gathered from the official website of the customer service centre of China's railway (www.12306.cn). This website offers precise information on train operations, which includes prices, transit stations, and dwell times. To iron out the possible effects of operational fluctuations, we mined the information of all HSR trains transiting any city of the YRD region on a fixed day (February 24th, 2014). For every train, we recorded cities of origin and destination, transit cities and their dwell times. The end product that details the situation of transits (dwell times) is a city-train matrix of 657 trains across the 22 cities. Applying our method, the transformed intercity network is shown in Figure 2.2, in which edge thickness reflects the flow strength of city-pairs and node size reflects cities' volumes of passenger flows.

The transformed network only connects cities along the HSR network; therefore, only 207 valid (nonzero) intercity connections in terms of HSR passenger flows are presented in this network. The largest flow is between Shanghai and Nanjing, with 344 HSR trains operating between them daily; the smallest flow is between Changzhou and Quzhou, where only two HSR trains operate on a daily basis. Paralleling the central corridor of the YRD urban agglomerations (Gu et al., 2007), we can observe the geographic concentration of passenger flows along the Nanjing-Shanghai-Hangzhou-Ningbo belt, where the main HSR lines lie, i.e. Shanghai-

Nanjing HSR line, Shanghai-Hangzhou HSR line and Hangzhou-Ningbo HSR line. In addition, Shanghai, Nanjing and Hangzhou emerge as the most connected cities in the network of passenger flows; Suzhou (one of the most dynamic cities that attract foreign direct investment in YRD (Zhao and Zhang, 2007)), Ningbo (the main gateway city in the southern part of the YRD) and Hefei (the administrative and economic centre of Anhui province that has been looking to join the YRD regional collective) are three sub-centre nodes of the network of passenger flows.

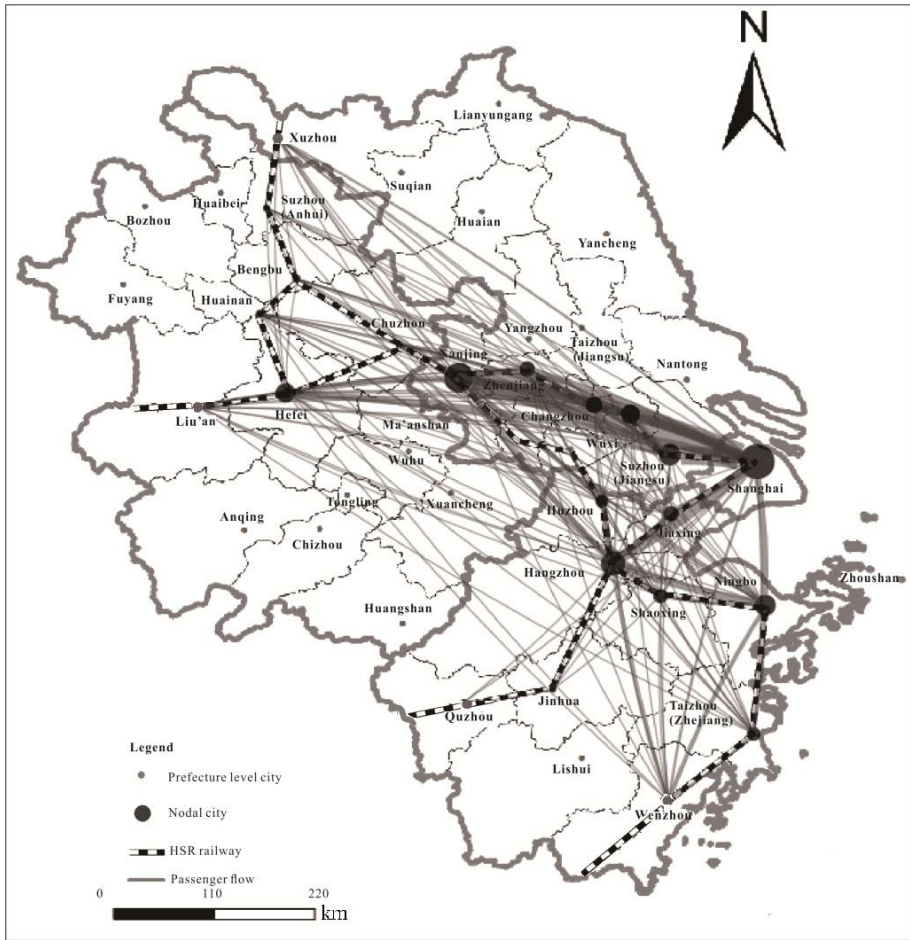


Figure 2.2. The transformed network of passenger flows within the Yangtze River Delta

2.4.2 Comparison between the original network generated by the proxy of the number of daily trains and the transformed network

Our alternative approach is devised to address the obstacle of overly flat structures produced by train schedule-based methods for assessing urban networks. Here, we examine the changes put forward by applying the transformation set out in section 2.3 by comparing original and transformed networks at the level of nodes, linkages, and network structures.

We first offer a direct comparison of cities' degree centralities in both networks (Figure 2.3). Degree centrality is a measure of nodes' position, which represents the (valued) number of passenger flows of cities. The first obvious change to note is that the degree centralities of a range of cities, which can be separated into two categories, seem lower in the transformed network. The first category is Nanjing, the sub-centre city within the YRD. There are 444 HSR trains operating across Nanjing on a daily basis, which is almost the same as the number of HSR trains operating across Shanghai (490 per day). However, part of these trains only transit across Nanjing, while most of them depart from or have their final stop at Shanghai. That means Shanghai contributes most of the passengers, whereas Nanjing only contributes part of the passengers. In this case, Nanjing's position in the original network is obviously overestimated. The other category includes Suzhou (Jiangsu), Wuxi, Changzhou, Zhenjiang, Shaoxing, and Xuzhou, which are transit cities in main corridors: Suzhou (Jiangsu), Wuxi, Changzhou, and Zhenjiang are on the Shanghai-Nanjing HSR railway line, Shaoxing is on the Hangzhou-Ningbo HSR railway line, and Xuzhou is on the Beijing-Shanghai HSR railway line (Figure 2.1). This is consistent with the theoretical illustration of over-estimations of the position of transit cities in section 2.2. On the other hand there are also nodes becoming relatively more important in the transformed network. The most dramatic change is the higher rankings of Hefei, Ningbo, Hangzhou and Wenzhou.

Second, Figure 2.4, in which edge thickness reflects the flow strength of city-pairs, maps the 15 most connected city-dyads in the original network as well as the transformed network. City-dyads along the Nanjing-Shanghai HSR line are the most connected city-dyad – with the exception of Shanghai-Hangzhou – in the original network (Figure 2.4a). This reflects the fact that any pair of cities along the Shanghai-Nanjing HSR line will have similar number of intercity trains. Compared with the pattern of concentrating on the Shanghai-Nanjing corridor in the original

network, the backbone of the transformed network (Figure 2.4b) consists of the key cities along the Nanjing-Shanghai-Hangzhou-Ningbo belt, which is more consistent with the central corridor of YRD urban agglomerations (Gu et al., 2007). More specifically, the original network tends to overvalue intercity connections, such as Nanjing-Wuxi and Shanghai-Zhenjiang, along the Nanjing-Shanghai HSR line, but on the other hand there are also intercity connections that are being undervalued. These connections can be divided into two simple categories: the connections between Shanghai and sub-centres that are not on the Shanghai-Nanjing corridor (i.e. Hangzhou, Ningbo and Hefei), and the connections between pairs of proximate sub-centres (i.e. Nanjing-Hefei, Hangzhou-Ningbo). In the latter cases, the dense flows of people between Nanjing and Hefei – the closest pair of provincial capitals in China – are apparent, especially in the context of the regional integration of Yangtze Economic Zone. The Hangzhou-Ningbo corridor, along which long-running and dynamic peri-urbanisation process has occurred (Webster and Muller, 2002), typifies the cooperative pattern of core city (Hangzhou) and sub-centre & port city (Ningbo): Ningbo – Hangzhou’s vicinity having more attractive labour, land and tax costs – attracts many manufacturing functions to moving from Hangzhou with keeping R&D and sales functions in Hangzhou (Webster et al., 2003); on the other hand, Ningbo’s deep-sea container port provides Hangzhou with more wide international market and hinterland. This provides fundamental bases for the dense intercity flows between Hangzhou and Ningbo.

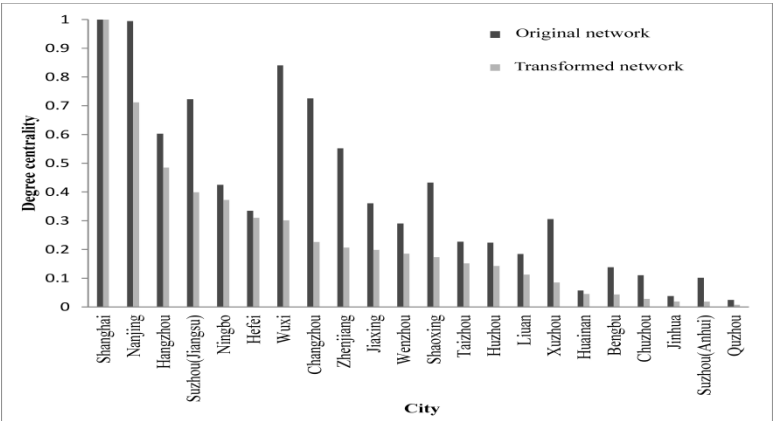


Figure 2.3. Cities’ degree centralities in the original network and the transformed network

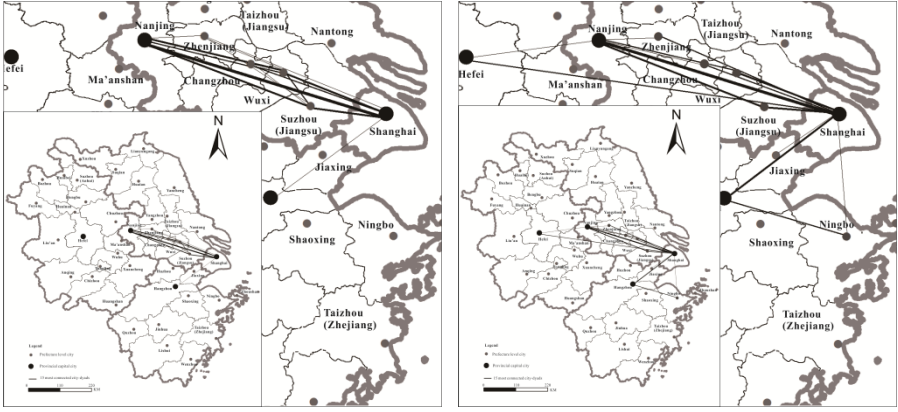


Figure 2.4. The 15 largest intercity links in the original network and the transformed network (a-left: The original network; b-right: The transformed network)

And third and finally, to explore the structural difference between both networks, we compare the rank-size distributions of cities' degree centralities. The posited flatter structure of the original network is indeed shown by the much steeper drop-off in the cities' degree centralities in the transformed network, shown in Figure 2.5. We calculate the integration of rank-size curve of cities' degree centralities to measure the flat degree of both networks. After normalizing cities' ranks into the interval $[0,1]$, the flattening ratio (F) of networks can be calculated as:

$$F = \int_0^1 L(X) dX \quad (11)$$

where the function $Y = L(X)$ represents the rank-size curve. The flattening ratio varies between 0 for completely even and 1 for completely uneven networks. In our measures, the flattening ratio of the original network (0.39) is much higher than the flattening ratio of the transformed network (0.23): more precisely, the flattening ratio of the transformed network has decreased to 60% of the original flattening ratio in the case of the HSR network within the YRD.

2.5 A benchmark test using the data on Weibo users' intercity movements

In order to evaluate the validity of our method, we need compare the transformed network to a measure of actual flows of people. Due to the difficulty of finding a corresponding database of flows of HSR passengers, here we utilise a database of Weibo⁴-users' intercity movements, which represents a specific part of tangible

flows of people. It can be argued that the flows of HSR passengers and Weibo-users' intercity movements have similar characteristics. The reason is that they serve relatively similar user markets: the market of HSR is mainly oriented to business travel and leisure tourism of citizens with certain economic means (Wu et al., 2013; also see Zheng and Kahn, 2013: 'poor rural migrants would not choose bullet trains'); and most of social media users are young adults who have certain economic capacities that include the use of smartphones. Both the collection and subsequent transformation of Weibo data follow the methodology developed in Zhang et al. (2016); here we summarise the main tenets.

Similar to other social media services (such as Facebook and Gowalla), Weibo users are allowed to share their location through a mobile application that is commonly known as a geo-tagged server, thus generating massive location records contributed by millions of users. We transform the geo-tagged information into individual travelling trajectories by connecting users' registered place and their visited cities. In practice, we employ an Application Programming Interface (API) provided by Weibo to crawl all Weibo-users' travel records submitted within the YRD region from March to August 2014. This dataset contains 3 million intercity footprints; each record represents a directional intercity flow of a person. Finally, the directional network of Weibo users' flows was converted to an undirected one by combining opposite directional links.

By means of a Pearson correlation measure, we first compare the similarity between both networks (the transformed network and the original network) and the benchmark network of Weibo-users' intercity movements in terms of cities' connectivities. The correlation coefficients show that, in general, there is a more similar relationship between the transformed network and the benchmark network ($r = 0.87$ at the 0.001 significance level) which exceeds the coefficient for the original network ($r = 0.76$ at the 0.001 significance level). We also plot the rank-size distribution of cities' degree centralities in the Weibo-users' movements network (Figure 2.5) to compare networks' structural similarity. An intuitive sense is that the curve of the Weibo-users' network is closer with the curve of the transformed network. We mathematically compute the flattening ratio of the Weibo-users' network (0.29), which is indeed closer with the flattening ratio (0.23) of the

transformed network.

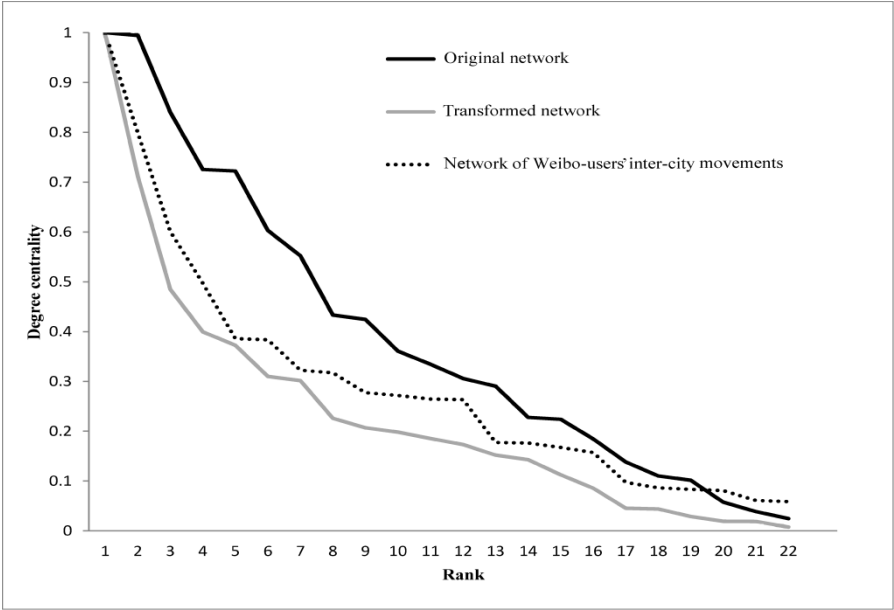


Figure 2.5. The rank-size distributions of cities' degree centralities in the original network and the transformed network

2.6 Conclusions

The purpose of this paper has above all been methodological: we propose to rethink some of the discrepancies between physical infrastructure networks and actual flows occurring in these networks, focusing on the lens of the railway system. We did so by (1) assessing some limitations in commonly used measures of intercity rail connections and (2) setting out an alternative approach to approximating passenger flows in railway networks.

Previous empirical research on measuring intercity linkages through the lens of railway infrastructures has tended to use proxy strategies, where (1) measuring the potential for interactions by train and (2) measuring the volume of trains making intercity connections stand out as the two main strands due to the lack of data on actual passenger flows. However, the method of measuring the potential for interactions only mirrors the quality or efficiency of train transport infrastructures itself rather than considering the 'direct demand' for intercity linkages. And, the

proxy of using the volume of trains structurally predetermines a flatter structure in the urban hierarchy than warranted.

This research has shown that ‘dwell time’ at train stations reflects the length of the alighting and boarding process, and we use this insight to estimate actual interaction through the application of a bimodal network projection function. The empirical application to the high-speed railway (HSR) network within the Yangtze River Delta (YRD) region revealed that the transformed network varies from the original network to a large extent: (i) the positions of transit cities along main transport corridors in the YRD urban system are driven down while some arguable sub-central cities stand out; (ii) intercity connectivities tend to be more hierarchical; and (iii) the flattening ratio has decreased to 60% of the original flattening ratio. Moreover, the validity of our method has been evaluated through a comparative analysis with Weibo-users’ intercity movements, verifying that the transformed network more parallels tangible flows of people.

We believe our paper makes two contributions to the literature. The first is to remind researchers to re-examine the validity of proxy strategies when measuring intercity transport flows. With the exception of recent research on airline networks in the context of the world city literature, relatively limited attention has been paid to the degree to which these infrastructure networks reflect the actual flows they undergird. In this regard, this article offers empirical evidence for the structural determinism of using train networks per se, as these tend to result in flatter networks. Second, the central contribution of this paper has been to set out an alternative method of approximating actual flows in railway networks, which permits practical applications in simulating flows of railway passengers in other cases.

Apart from empirical applications in other cases, further research issues also include: discussing other modes of constructing equations, discovering alternative perspectives to approximating actual flows in railway networks, investigating the biases between the infrastructure provision and corporeal flows in other networks such as Internet backbone and bus networks, and studying how data on these infrastructure operations can be adapted to better reflect actual intercity interactions.

Notes

1. This hypothesis is, of course, implausible in any of the transit cities. However, the operational logic of trains is vested in there being round-trip. In this case, the average volumes of boarding and alighting in a daily basis will be roughly equal. For easy operationalisation, we adopt an equal weight for boarding passengers and alighting passengers in every transit city for a train.
2. In the Chinese context, HSR refers to train services with an average speed of 200 km/h or higher, which include D category trains (high-speed trains in conventional railways), G Category trains (high-speed trains in high-speed railways), and C Category trains (short intercity express trains).
3. The YRD has various boundaries according to different definitions and research purposes. Throughout this paper, we adopt the largest scope including Shanghai Municipality, Jiangsu Province, Zhejiang Province and Anhui Province, which is also in conformity with the administrative boundary of the Shanghai Railway Bureau.
4. With more than 212 million monthly active users and 93 million daily active users (see <http://goo.gl/ovGvYO>), Weibo is the most mainstream social media in China.

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3. Using location-based social media to chart the patterns of people moving between cities: The case of Weibo-users in the Yangtze River Delta

Zhang W, Derudder B, Wang J, Shen W and Witlox F. (2016) Using location-based social-media to chart the patterns of people moving between cities: The case of Weibo-users in the Yangtze River Delta. *Journal of Urban Technology* 23(3): 91-111.

Abstract

Urban-geographical research using location-based social media (LBSM) has itself been characterized by uneven geographies in that most studies deal with Europe and North America. This implies a relative dearth of studies focusing on countries such as China, and this in spite of the country having the largest number of Internet users in the world. This paper proposes to address this lacuna by showing the research potential of LBSM services associated with Weibo, by far the most popular online social microblogging and networking service in China. To this end, we map intercity connections within the Yangtze River Delta based on three million individuals' space-time footprints derived from Weibo. Empirical results reveal that the intercity connections derived from Weibo present both common and specific spatial patterns associated with intercity travel. We find that a small percentage of cities and city-dyads constitute the backbone of this intercity network. The dominant direction of individual flows tends to be from primary cities to sub-primary cities, and from peripheral cities to primary cities. In addition, city-dyad connectivities do not strictly follow cities' positions in terms of their centralities in the hierarchical distribution. Furthermore, the effects of administrative boundaries and cities' administrative level are significant. We benchmark these insights by re-examining our findings against the backdrop of the widely-documented polycentric developments in the Yangtze River Delta, which confirms the potential usefulness of LBSM data for analyzing urban-geographical patterns.

3.1 Introduction

In this era of ‘big data’, geo-referenced data have increasingly attracted interest from GIS scholars and become popular in geographical research. By collecting, creating, assembling, and sharing geographic data contributed by individuals, volunteered geographic information (VGI) (Goodchild, 2007) offers new avenues for exploring the geographies of user-generated content. Location-based social media (LBSM) – a special type of implicit VGI (Craglia et al., 2012) – such as ‘Foursquare’ and ‘Facebook Places’ combine social networking services and location sharing services, resulting in the explosion of rich, spatially-embedded information about users and their activities. As a consequence, there is a proliferation of research using LBSM over the last years, including the extraction of patterns of human mobility (see, e.g., Cho et al., 2011; Steiger et al., 2014), the detection of the emergence and subsequent spreading of epidemic diseases (see, e.g. Lampos and Cristianini, 2012), and the analysis of disaster responses (see, e.g. De Longueville et al., 2009; Sakaki et al., 2010). However, previous research using LBSM has itself been characterized by uneven and partial patterns. As a consequence, most studies only focus on some parts of the world, with many other regions remaining invisible (Graham et al., 2014).

Indeed, as Graham (2014: 100) points out, there are uneven geographies of user-generated information: ‘some people and places are left out of the digital and material augmentations that we produce and reproduce.’ LBSM research provides a powerful example of this observation: most studies on LBSM deal with Europe and North America, even though other world regions equally have vast numbers of Internet and LBSM users. This can be attributed to a number of overlapping social, economic, political, and regulatory barriers, which have collectively resulted in a relative dearth of studies focusing on these regions (Graham and Zook, 2011). A notable example is China, in which mainstream social media such as Twitter and Facebook are (made) unavailable because they violate the national government’s policy of Internet censorship (Liebelson, 2014) and content control, resulting in a relative lack of LBSM studies in spite of the country having the largest number of Internet users in the world (notable exceptions include Liu et al., 2014; Hjorth et al., 2012; Majid et al., 2013).

In this paper we seek to address this lacuna by exploring the potential of the LBSM service associated with Weibo, which is by far the most popular online social networking and microblogging service in China. To this end, we present a concrete application, i.e. we map intercity flows of people within the Yangtze River Delta (YRD) through LBSM data derived from Weibo. More specifically, the analysis draws on geo-referenced Weibo messages generated within the YRD, with a particular focus on the intercity movements of Weibo users. To demonstrate the usefulness of Weibo data for analyzing urban-geographical patterns, we first discuss the basic patterns of intercity connections by focusing on hierarchies and spatialities of nodes and linkages. Second, we re-examine the YRD's polycentric development using these results (Hall and Pain, 2006; Liu et al., 2016). The main objectives of this paper are therefore (1) to examine a potential data source for geographic LBSM research in the Chinese context, (2) to assess how Weibo can be used as a source for mapping urban-geographical information, and (3) to discover the polycentric patterns of intercity connections within the YRD.

The remainder of this paper is organized as follows. The next section provides an overview of geographical research using LBSM. We briefly introduce LBSM, outline the remit of previous empirical studies, and discuss the uneven geographies of previous research. After that, we describe our data acquisition and processing, and the methods of analyzing the data. This is followed by a section exploring patterns of intercity connections and polycentric development in the Yangtze River Delta. Finally, we present our main conclusions and discuss some avenues for future research.

3.2 LBSM data in geographic research

3.2.1 LBSM: Definition and potential as a data source

In recent years, we have seen the emergence of a number of social media services through which users can create and exchange user-generated content under the broad umbrella of Web 2.0 (Kaplan and Haenlein, 2010). Using these online platforms, it has become straightforward for users to present or self-disclose personal information in cyberspace (Devriendt et al., 2008), such as sharing ideas, work and personal activities, and feelings. Accompanied by the development of location-acquisition

technology such as GPS and Wi-Fi, location-based services have become a burgeoning segment of social media (Zheng, 2011). By adding this locational dimension, social media applications can produce information about where an IP-capable mobile device is located, hence the term location-based social media (LBSM). LBSM provides the opportunity to produce location-embedded information by means of a variety of social media services, such as blogs (e.g., Blogger), content communities (e.g., Flickr), and social networking sites (e.g., Facebook). Some compelling examples include Facebook Places, which displays the whereabouts of users and their friends on an interactive map; Google+ that enables users to discover nearby places and get place recommendations from their friends; and Foursquare which encourages users to share personal location information. Given the popularity of social media, millions of pieces of geographic information are contributed by millions of citizens, thus resulting in a new and interesting ‘big data’ source for mapping geographical patterns. As Hardy et al. (2012) argue, geographic information can now be collected, created, shared, and assembled by individuals via the Internet much more easily than via traditional mechanisms such as remote sensing, censuses, and surveys.

From a research perspective, the biggest advantage of LBSM data is that they have the potential to combine ‘data volume’ and ‘data depth’ (Manovich, 2011; Sui and Goodchild, 2011). That is, researchers can not only capture large volumes of data, but also fine-grained attributes giving information about what, when, and where things happened, thus enabling largescale yet fine-grained spatio-temporal studies. For example, in Stefanidis et al. (2013) over 300,000 tweets about Syria (collected between 10 and 17 July 2012) were processed to identify global virtual communities around specific interests.

Another interesting feature of LBSM data is that they contain information on both geographic positions and a range of social attributes, which makes it possible to examine a range of socio-spatial correlates (Scellato et al., 2011), such as predicting individual locations from users’ social networks (Backstrom et al., 2010) and inferring social ties from geographic coincidences (Crandall et al., 2010). Moreover, LBSM often provides real-time data that enables monitoring spatiotemporal patterns as they unfold, which is particularly relevant in the field of disaster and contagion

management (Lampos and Cristianini, 2012). And finally, it is also worth mentioning that it is in principle easier to collect and process data through online platforms when compared to more conventional methods of data gathering where access to data resources can or tends to be privileged (Poorthuis et al., 2014).

3.2.2 Previous geographic research using LBSM

Although LBSM data have been used in very different strands of research, from a geographical point of view two broad fields stand out, i.e. (1) the understanding of human spatio-temporal-social behaviour and (2) event predictions.

The first strand of research draws on the fact that LBSM may provide more insight into individual activities, associated social attributes, venues, and motivations compared to other ‘big data’ sources (e.g. cell phone data and GPS trackers; Doyle et al., 2014; Järv et al., 2012). Such studies tend to have a number of related objectives: (i) understanding human movement and mobility patterns in daily activities or long-range activities (e.g. Sun et al., 2013); (ii) predicting individual locations based on historical records of travel, social, and spatial attributes (e.g. Backstrom et al., 2010); (iii) studying socio-spatial correlations in individual behaviour (e.g. Scellato et al., 2011); and (iv) mapping the spatial (and temporal) distribution of LBSM activities, which can be envisaged as a reflection of the overall geographies of LBSM users and their behaviour (e.g. Röler and Liebig, 2013).

A second domain deals with the real-time mirroring of the spatio-temporal unfolding of ‘events,’ facilitated by the presence of the time dimension in LBSM data. As users post event-related contents in LBSM (e.g., the streamlining of comments through the use of hashtags on Twitter), it becomes possible to detect and monitor these events. For example, disasters (De Longueville et al., 2009; Sakaki et al., 2010), disease (Lampos and Cristianini, 2012), and concert tours (Senaratne et al., 2014) have been used in the real-time surveying and tracking of events. A recent example of detecting events based on real-time spatio-temporal information from LBSM is Boecking et al.’s (2015) study of events surrounding the Egyptian revolution of 2011 on the basis of Twitter data, showing that the information from Twitter provide an important signal for predicting societal-scale unrest.

3.2.3 The uneven geographies of previous LBSM studies

Although it is clear that LBSM is increasingly recognized as a valuable data source, LBSM itself has geographies that bear a complex relation with the underlying realities it seeks to capture. LBSM data only reveals the information from the people who create the data, and is as such not randomly generated. Hacklay (2012) and Li et al. (2013) have argued that above all highly-educated and higher-income groups (with an additional bias towards men) are likely to share information on social media. In Kent and Capello (2013), it has been shown that above all relatively younger people residing in rental properties contributed LBSM information during a wildfire.

Furthermore, urban areas have more intensive LBSM activities on a per capita basis than rural areas (Hecht and Stephens, 2014), while tourism hotspots obviously attract more ‘check-ins’ in LBSM (Liu et al., 2014). Wiersma (2010) has indicated that these biases and the subsequent non-randomness are reflective of a much broader ‘digital divide’ impinging on LBSM-based research. A specific, macro-scale example of this divide is the tendency in LBSM research to focus on Europe and North America, which is in turn reflective of the fact that some of the most well-known LBSM dominate the market in these regions.

Graham (2014) explores these uneven Internet geographies through the concept of data shadows and digital divisions of labor (see also Graham et al., 2014). In addition to his observation that a lot of knowledge from or about the Global South is not on the map of user-generated information, he also notes that Internet penetration rates are not the main determining factor influencing these uneven patterns. Rather, it is above all ‘literacy and education, digital architecture, physical infrastructure, governance of online communities and platforms, cultural, religious, gendered, and other socially constructed barriers, politics and political interference, and language’ that contribute to the ‘shadows’ of Internet geographies (Graham 2014: 106). The geography of LBSM – a specific type of user-generated information – is also characterized by such uneven patterns, especially in a context of the (imposed) unavailability of mainstream social media in some countries. Upon inspection of the two most visited websites and/or social media websites in different countries through the Alexa¹ data, it becomes clear that Facebook is clearly the most popular

(social media) website in most of the world, and especially in America and Europe. There are, however, notable exceptions. A well-known example is that of Mainland China, where the government blocks access to Facebook and Twitter (Liebelson, 2014). Political borders thus produce and deepen uneven patterns of LBSM use. However, these ‘uncharted’ regions are not necessarily characterized by the absence of LBSM services, as there are alternatives that work along similar lines. In China, for instance, services such as WeChat and Weibo dwarf all LBSM-alternatives and in this paper, we tap one of these sources to engage in an analysis of mobility patterns in the Yangtze River Delta.

3.2.4 Deriving users’ intercity connections from geo-tagged records

The increased popularity of ‘network thinking,’ which has been formulated in different disciplines and often serves different purposes (Dehmer and EmmertStreib, 2009; Scott and Carrington, 2011), has promoted urban geographers’ interests in mapping urban networks at multiple scales ranging from the global (e.g. Taylor and Derudder, 2016) to national (e.g. Zhao et al., 2015) and regional (e.g. Hall and Pain, 2006). Most of the empirical research is built upon the spatial logic which Castells (1996) termed ‘the space of flows.’ A major line of research in this respect is to map the ‘space of flows,’ for example by analyzing infrastructure connections (e.g. Derudder and Witlox, 2008; Mahutga et al., 2010) and linkages within corporate organisations (e.g. Alderson and Beckfield, 2004; Taylor et al., 2014). More specifically, these approaches focus on what Castells (1996) has identified as the first layer and second layer of ‘the space of flows,’ i.e., the material support and the social practices underlying intercity connections. LBSM seems to hold great potential in this research domain, as it is possible to link social practices to intercity engagements as visible in users’ ‘geo-tagging’ their movements between their hometown and a range of other places.

3.3 Deriving intercity connections from Weibo

Weibo, which literally means ‘microblog’ in Mandarin, is China’s main online social networking and microblogging service, and can best be described as a hybrid of Twitter and Facebook. With more than 93 million daily active users and almost 212 million monthly active users (see <http://goo.gl/ovGvYO>), Sina’s version of

Weibo has become the most important microblog in China. In March 2014, Sina Corporation used its market dominance to change the original name ‘Sina Weibo’ into ‘Weibo’ to prompt users and investors to forget there are other microblogging services. In this paper, Weibo refers to what was initially called ‘Sina Weibo.’

Similar to Twitter, Weibo users are allowed to post a short text (with a 140-character limit) expressing impressions, information, and daily activities. More importantly, users can also share their location through a mobile application that is commonly known as a ‘geo-tagged’ service. A geo-tagged post, therefore, contains spatial and temporal information, as well as a short message referring to status, emotion, or location-related information. The geo-tagged records of millions of users can be considered to be a source of information reflecting users’ socio-spatio-temporal behaviour. In order to facilitate programmatic access to the service, Weibo provides a public application programming interface (API) for application developers to search and download these messages, and this is what we have done in our research in order to analyse Weibo users’ intercity tagging.

In our study, we focus on the Yangtze River Delta (YRD), which is situated at intersection of the Yangtze River and the coast, including a municipality directly under the central government (Shanghai), three provincial capital cities (Nanjing, Hangzhou, and Hefei), and 37 prefecture-level cities. The YRD region is one of the most developed regions of China. With 3.6 percent of China’s total land area, it generated 23.5 percent of Mainland China’s Gross Domestic Product in 2014, and houses over 227 million people, which is 16.6 percent of the 2014 census population of Mainland China. The YRD is also a typical polycentric mega-city region as per Hall and Pain (2006), as it contains multiple central cities such as Shanghai, Nanjing, Hangzhou, and Hefei. These cities are strongly interlinked through dense motorway and high-speed railway networks. Furthermore, a range of overlapping and diverging urban functions and development strategies implemented by local governments (Gu et al., 2010) have resulted in a polycentric labour market.

The Weibo API was used to gather the geo-tagged records submitted within the YRD region between September 2013 and April 2014. The dataset contains 27.53 million geo-tagged records, where each record provides users’ basic information

(such as user-ID, place of registration, gender, and the number of friends), post content, and spatial (geographic coordinates) and temporal information on the post. Figure 3.1 presents the ‘heat map’ of these geo-tagged records, in which major urban centres such as Shanghai, Nanjing, Hangzhou, and Hefei are clearly visible. In this map, we can also observe the geographic concentration of Weibo users’ activities on the areas surrounding Taihu Lake where the core cities of the YRD are located. In addition, there is a very obvious pattern along transport infrastructures, as shown from the highlighted lines that correspond with main traffic arteries connecting cities. And finally, the spatial distribution of check-in points within cities parallels patterns of sprawl within an urban area, especially in the eastern parts of the YRD. Thus it can be observed that Suzhou, Wuxi, and Changzhou have almost been merged into a single metropolitan region.

When studying the geography of Weibo’s geo-tagged records, it is clear that most of the uneven distribution can be traced back to the population distribution in the YRD. This means that simply mapping geo-tagged records would produce results that largely replicate the population distribution. To identify which cities are ‘really’ more attractive for geo-tagging, the effect of population size can be controlled through a data normalisation process in which cities’ geo-tagged records are divided by cities’ population size. Table 3.1 shows the rank of cities in terms of the per capita number of registered users and the per capita number of geo-tags. Larger cities such as Hangzhou and Nanjing have more Weibo-users and attract more geo-tagging activities, while smaller cities such as Bozhou and Suzhou (Anhui Province) are less important.

Interestingly, Weibo data provide information on users’ geo-tagged places, as well as information on their place of registration, which normally correspond to their hometown or permanent residence.² In order to facilitate the transformation of the original Weibo data into data on intercity travel in the YRD, two data transformations are needed: (i) replacing the coordinate information of tagged sites with corresponding city names following municipalities’ official delineation; and (ii) deleting geo-tagged records in which places of registrations are outside of the YRD region. The resulting dataset includes more than three million geotagged records.

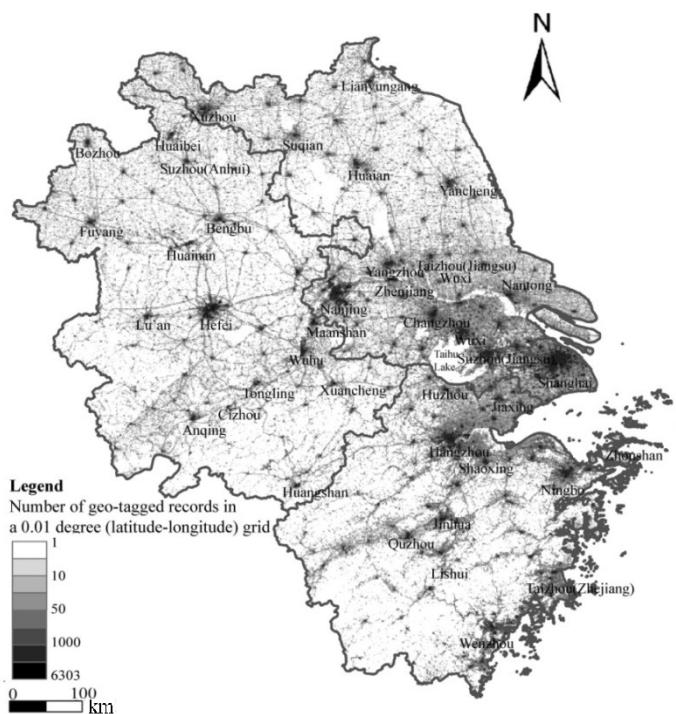


Figure 3.1. The heat map of Weibo users' geo-tagged records submitted within the YRD region between September 2013 and April 2014

Table 3.1. Rank of cities in terms of per capita number of registered users and per capita number of geo-tags (10 biggest and smallest cities are shown)

Per capita number of registered users		Per capita number of geo-tags	
Rank	City	Rank	City
1	Nanjing	1	Nanjing
2	Hangzhou	2	Hangzhou
3	Shanghai	3	Shanghai
4	Hefei	4	Wuxi
5	Ningbo	5	Suzhou(Jiangsu)
6	Wuxi	6	Hefei
7	Suzhou(Jiangsu)	7	Ningbo
8	Cangzhou	8	Cangzhou
9	Jiaxing	9	Jiaxing
10	Tongling	10	Tongling
...
32	Cizhou	32	Huaian
33	Huaian	33	Huaibei
34	Yancheng	34	Chuzhou

35	Chuzhou	35	Yancheng
36	Suqian	36	Suqian
37	Anqing	37	Anqing
38	Liuan	38	Liuan
39	Fuyang	39	Fuyang
40	Suzhou(Anhui)	40	Suzhou(Anhui)
41	Bozhou	41	Bozhou

To explain how we turned geotagged data into intercity data, we make use of a hypothetical example of a data record:

*{<place of registration=City r>, <City-a, Dec.3>, <City-r, Jan.4>, <City-r, Jan.7>
<City-b, Feb.8>, <City-c, Feb.9>, <City-r, Feb.15>, <City-d, Mar.12>, <City-r,
Mar.17>, <City-b, Mar.22>, <City-c, Apr.10>, <City-r, Apr.13>}*

This data record describes the trajectories of a Weibo user residing in city (*City-r*) to four cities (*City-a*, *City-b*, *City-c*, and *City-d*), two of which were visited twice. The purpose, now, is to map out links among the five cities. To this end, we adopt a star network topology to connect individual geo-tagged cities and the place of registration.

In other words, the place of registration is used as the central node that acts as a source of producing links, while other visited cities are considered to be peripheral nodes, which generate direct connections between the registered city and visited cities. The direction of connections is assigned from the registered city to visited cities, and the strength of links is set according to the number of times a city is geo-tagged. In our example, the projected intercity network is presented in Figure 3.2, where edge width is proportional to the strength of linkages, and nodal size is proportional to the total strengths of linkages a node has with all other nodes (which in network analysis is called degree centrality). This directed star topology was applied to our entire dataset, and aggregation result in a geographical picture of intercity movements in the YRD. We discuss these patterns in the next section, with the overview and interpretation of findings serving our meta-objective of showing how LBSM technologies can be used in a variety of urban literatures.

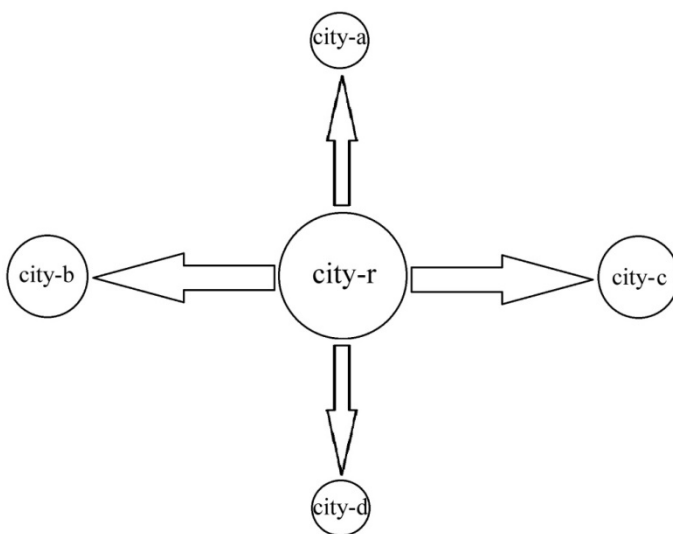


Figure 3.2. Inferred intercity network built on the directed star topology

3.4 Results

Our discussion of results focuses on the hierarchies and spatialities of nodes and linkages, and the polycentric pattern that can be discerned within them. To assess cities' positions in the network, we focus on their degree centrality, which can be disaggregated in out-degree (total of outgoing ties, i.e. number of 'check-ins' elsewhere from people living in the city) and in-degree centrality (total of incoming ties, i.e. 'check-ins' in the city from users living elsewhere). Similarly, we explore total strength of connections, as well as their disaggregation in outgoing and incoming links. And finally, we examine the degree of polycentricity visible in these connections by drawing on the procedure developed in Hanssens et al. (2014).

3.4.1 Analysis of cities

Figure 3.3 plots the rank-size distribution of the different measures of degree centrality using a log-log scale. The graph suggests the presence of a power-law distribution, a recurring feature in urban systems (Gabaix, 1999): a small percentage of cities constitute the backbone of this intercity network. Figure 3.4 ranks cities in terms of their out-degree centrality, in-degree centrality, and overall degree centrality.

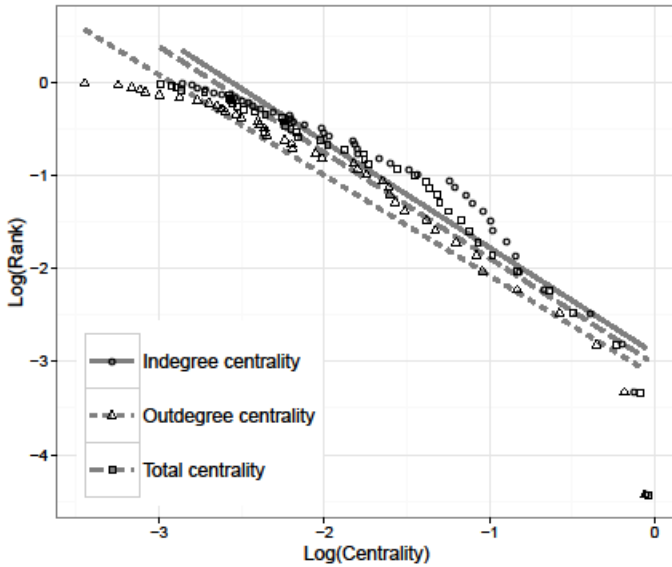


Figure 3.3. Log-log scale plot of the distribution of city's centrality

Our results point to an imbalance between cities' outward and inward links. Wenzhou, Xuzhou, Wuhu, Jinhua, Anqing, Zhenjiang, Suqian, Ma'anshan, Chuzhou, and Huangshan (shown in bold in Figure 3.4) in particular exhibit a remarkable difference between in-degree centrality and out-degree centrality. The first point to make here is that primary cities (i.e. Shanghai, Nanjing, and Hefei) are net-outflow cities. An exception is Hangzhou, which has more inward flows. This can be explained because of its role as tourist hotspot: Hangzhou is widely known as one of the most beautiful cities in China for its stunning scenery and various historical sites, often chosen as a holiday destination for individuals, families, and tour groups. As one of China's most popular tourist destinations, it draws over 90 million visitors every year (Hangzhou statistical yearbook data of 2014), which helps explain that it is a net-inflow city despite being a primary city within the YRD. The second point is that cities just below the leading cities tend to be net-inflow cities – whereas the least connected cities tend to be net-outflow cities. This is clearly reflected in the trend from the rank of total degree centrality to the rank of difference between in-degree and outdegree centrality in Figure 3.4.

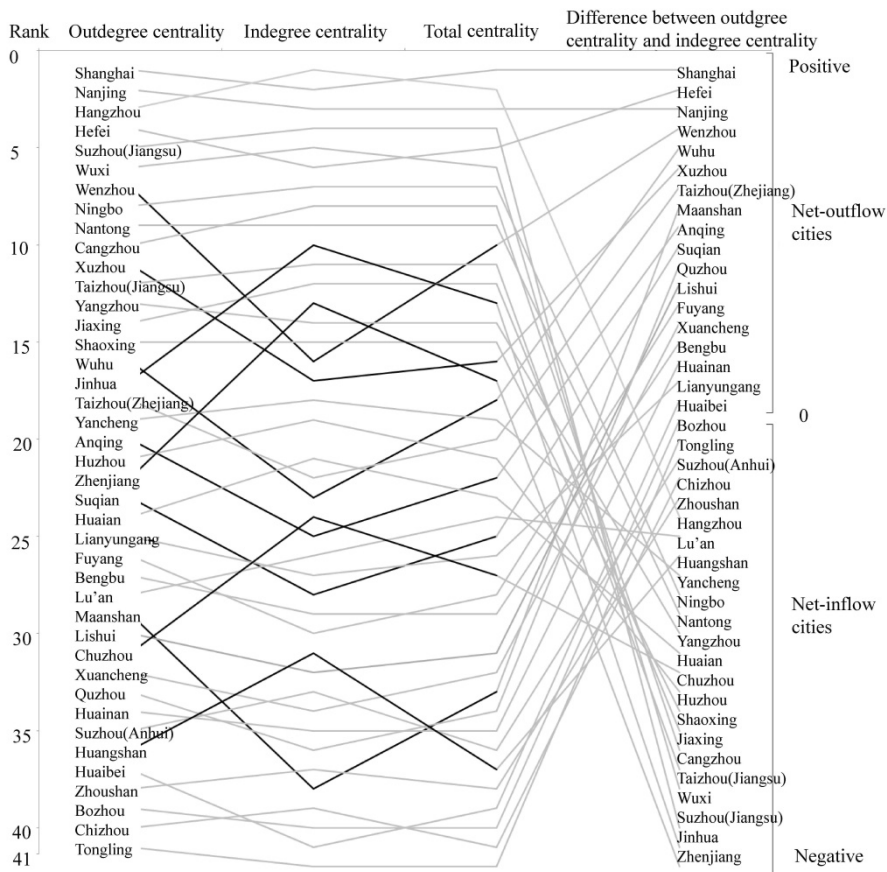


Figure 3.4. Cities' ranks in terms of their outdegree centralities, indegree centralities and total centralities, and the category of net-outflow cities and net-inflow cities

3.4.2 Analysis of intercity links

Intercity links can be analysed from three different perspectives: unidirectional links which represent either outgoing or incoming links, gross links which represent the aggregation of outgoing and incoming links, and net links which represent the difference between outgoing and incoming links. In our discussion, we focus on the 20 most important city-dyads as shown in Table 3.2. Shanghai has the strongest connections with other cities for both unidirectional links and gross links, reflecting its central (economic and logistic) position in the YRD. In addition, links between core cities – with the exception of Hefei – and other cities almost entirely make up the 20 most important unidirectional and gross intercity connections. Wuxi-Suzhou

(Jiangsu Province) is an exceptional city-pair produced by two major and adjacent economic centres in the YRD. However, the links between Shanghai, Nanjing, and Hangzhou do not occupy the primary positions in the ranking of city-dyad connectivities: it is the links between core cities and sub-central cities – i.e., Shanghai-Suzhou (Jiangsu Province), Hangzhou-Ningbo, Nanjing-Suzhou (Jiangsu Province), Shanghai-Wuxi, and Wenzhou-Hangzhou – that make up the three most important unidirectional and gross intercity connections. This suggests that intercity relations do not simply reflect cities' centralities. Furthermore, the unidirectional links and net links also reveal that the main direction of links tends to be from primary cities (i.e. Shanghai, Nanjing, Hangzhou, and Hefei) to other cities within and between provinces.

Table 3.2. The top 20 city-dyads for intercity unidirectional links, gross links, and net links

Rank	Unidirectional links	Gross links	Net links
1	Shanghai→Suzhou(Jiangsu)	Shanghai—Suzhou(Jiangsu)	Shanghai→Wuxi
2	Shanghai→Wuxi	Ningbo—Hangzhou	Shanghai→Taizhou(Jiangsu)
3	Wenzhou→Hangzhou	Nanjing—Suzhou(Jiangsu)	Shanghai→Suzhou(Jiangsu)
4	Hangzhou→Jinhua	Shanghai—Hangzhou	Wenzhou→Hangzhou
5	Shanghai→Hangzhou	Hangzhou—Shaoxing	Hangzhou→Jinhua
6	Ningbo→Hangzhou	Wenzhou—Hangzhou	Nanjing→Zhenjiang
7	Hangzhou→Shaoxing	Hangzhou—Jiaxing	Shanghai→Nantong
8	Hangzhou→Jiaxing	Hangzhou—Jinhua	Wenzhou→Jinhua
9	Hangzhou→Ningbo	Shanghai—Wuxi	Shanghai→Zhenjiang
10	Nanjing→Suzhou(Jiangsu)	Nanjing—Nantong	Shanghai→Cangzhou
11	Suzhou(Jiangsu)→Nanjing	Nanjing—Wuxi	Nanjing→Taizhou(Jiangsu)
12	Nanjing→Nantong	Nanjing—Shanghai	Hefei→Lu'an
13	Nanjing→Wuxi	Shanghai—Nantong	Shanghai→Hangzhou
14	Shanghai→Nantong	Nanjing—Cangzhou	Hefei→Shanghai
15	Shanghai→Taizhou(Jiangsu)	Wuxi—Suzhou(Jiangsu)	Hangzhou→Shaoxing
16	Hangzhou→Shanghai	Nanjing—Yangzhou	Taizhou(Jiangsu)→Zhenjiang

17	Shaoxing→Hangzhou	Hangzhou—Huzhou	Nanjing→Huaian
18	Jiaxing→Hangzhou	Taizhou—Hangzhou	Shanghai→Yangzhou
19	Nanjing→Shanghai	Nanjing—Zhenjiang	Hangzhou→Jiaxing
20	Wuxi→Nanjing	Nanjing—Xuzhou	Hangzhou→Huzhou

That said, cities’ connectivities generally have an impact on the strength of city-dyad connectivities: the absolute strength of intercity relations is partly dependent on cities’ position in the hierarchical distribution (see Taylor and Derudder, 2016). In order to correct for this effect, we calculate a relative measure of intercity connectivity, derived from the residual analysis of the regression of a city’s linkages against nodal connectivities:

$$CAC_{a-i}=a+bCC_i \ (a \neq i) \quad (1)$$

Where CAC_{a-i} represents city a ’s connections with all other cities, and CC_i are these cities’ connectivities. The residual (i.e., the difference between the actual level of city a ’s connections with other cities and estimated connections derived from the regression model) defines the relative city-dyad connectivity. Specifically, a positive residual shows that city a is strongly connected with city i , while a negative residual shows that city a is weakly connected with city i .

First, we analyse the largest positive connections for every city through these residuals. Figure 3.5 presents the result for the most connected city-pairs. The first thing to note is that these intercity links tend to be intra-provincial connections, which are furthermore centered on provincial capitals. This observation is in line with the well-documented barrier effect of provincial borders in blocking multiple intercity flows, e.g., trade flows (Poncet, 2005), flows of goods (Jiang and Prater, 2002) and migration (Fan, 2007). Furthermore, this also provides a clear example of the effect of cities’ administrative level in China. A key exception is the Ningbo-Zhoushan city-dyad. This is because, as an adjacent city-pair between an island city and mainland city, the massive movement of people between Zhoushan and inland cities tend to go through Ningbo. Especially since 2006, both cities’ ports have merged into Ningbo-Zhoushan port, now one of the largest ports in China, thus promoting a further integration of resources that is visible in our data. Another exception is the Shanghai-Suzhou city-dyad. Both cities belong to the Wu dialect

area and have a common Wu cultural background resulting in a cultural integration; furthermore, as the closest city to Shanghai, Suzhou relies on Shanghai’s financial markets while Suzhou’s well-developed manufacturing and processing industries supports the development of Shanghai as an international metropolis; and finally, nicknamed ‘Venice of the East’ Suzhou has well-developed tourism resources, which gives it a role as a ‘backyard garden’ for many of Shanghai residents (Zou et al., 2001).

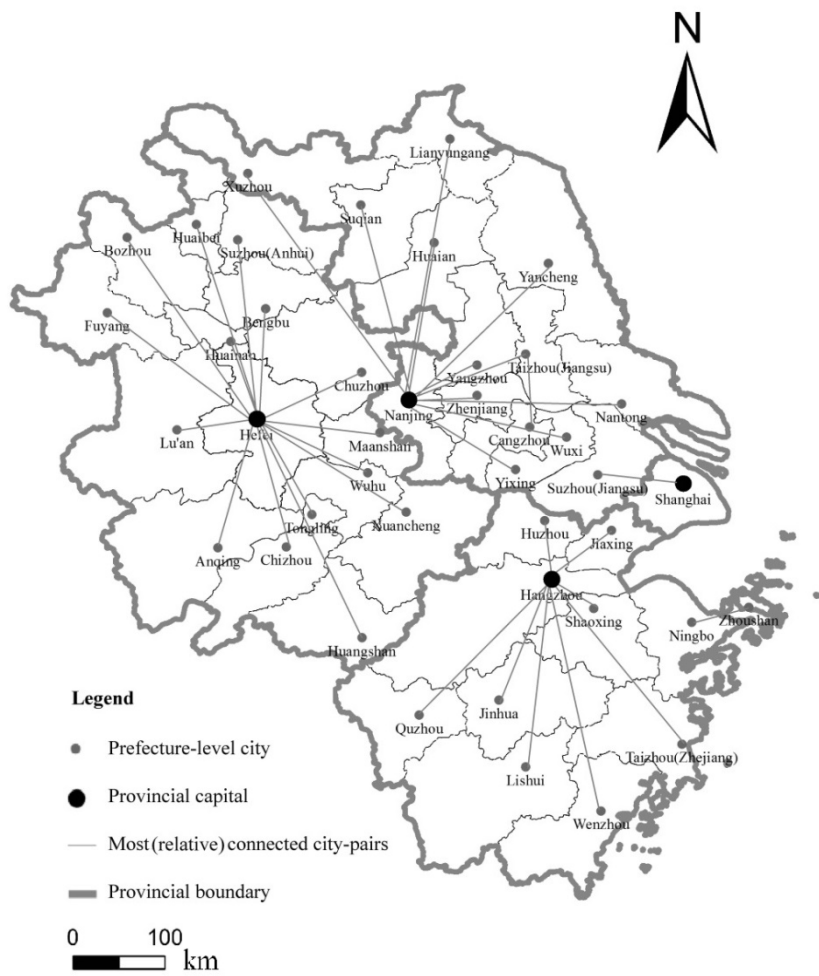
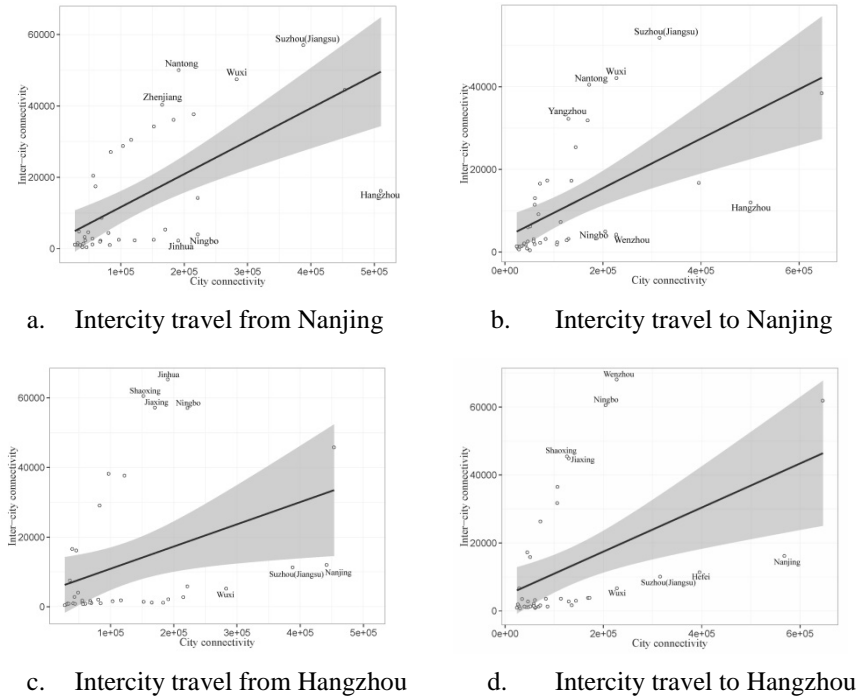
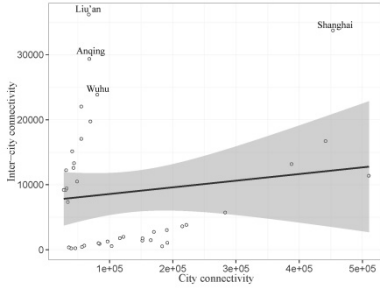


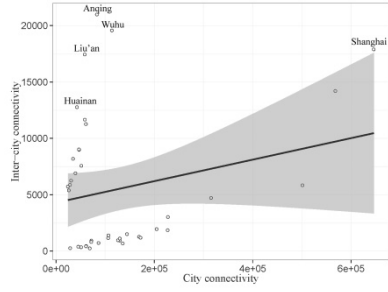
Figure 3.5. Most (relative) connected city-pairs in the network of Weibo-users’ intercity travel

And finally, we further illustrate relative intercity connections by zooming in on the example of Shanghai, Nanjing, Hangzhou, and Hefei. Results from the residual analysis display the strongest and weakest links of these cities, which are shown in Figure 3.6. The trumpet-shaped distributions of points again reflect that there is an obvious differentiation between strongly connected city-pairs and weakly connected city-pairs. All over-connected cities belong to the same province as the connected cities. When we look into the under-connected cities, it can be noticed that all obvious under-connected cities with Nanjing belong to Zhejiang Province while all obvious under-connected cities with Hangzhou belong to Jiangsu Province. For the relative connections of Hefei, Shanghai stands out as a well-connected city, which is an unusual result comparing with the connections of Shanghai-Nanjing and Shanghai-Hangzhou. This can be traced back to Anhui Province being the leading source of Shanghai's 'floating population' (temporary migrants). Finally, turning to the distribution of Shanghai's relative connections, we can see that there is no clearly discernable pattern of extreme differentiation in terms of positive links and weak links. This is different from other three cities, and reflects the wholesale influence of Shanghai within the YRD region.

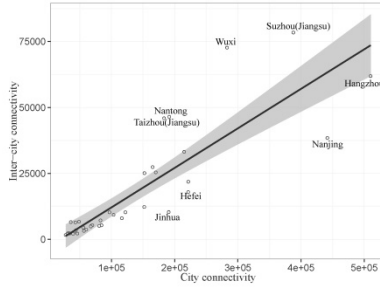




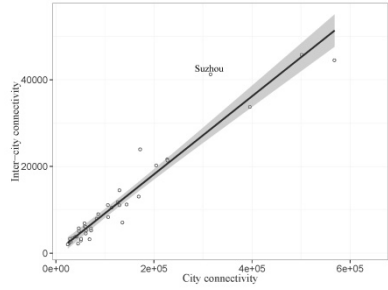
e. Intercity travel from Hefei



f. Intercity travel to Hefei



g. Intercity travel from Shanghai



h. Intercity travel to Shanghai

Figure 3.6. Relative connections of Nanjing, Hangzhou, Hefei, and Shanghai

3.4.3 Polycentricity in the Yangtze River Delta

To show the more concrete applicability of these findings in urban-geographical research, we conclude by using our LBSM-based data on intercity connections to explore the polycentric nature of the YRD. To this end, as a first step, it is necessary to define polycentricity in that there are different interpretations and different measurement approaches (Liu et al., 2016). In this paper, we are concerned with the extent to which cities' importance in the intraregional integration process exhibits a relatively balanced pattern, which is in line with the definition of functional polycentricity as put forward by Burger and Meijers (2012). We adopt the 'polycentricity index' (PI) developed in Hanssens et al. (2014), that is given by:

$$PI = \frac{2 - \frac{SD}{SD_{RS}}}{2} \text{ when } SD \leq SD_{RS} \quad (2)$$

$$PI = \frac{\frac{SD_{RS}}{SD}}{2} \text{ when } SD \geq SD_{RS} \quad (3)$$

where SD is the standard deviation of the dominance index (DI_i) of all cities within the YRD; and SD_{RS} is the standard deviation of the dominance index (DI'_i) of all cities in a dummy rank size distribution that has an equal number of cities. The values of PI are ranging from 0 (absolute dominance) to 1 (perfect polycentricity), with an intermediate benchmark at 0.5 (a rank-size distribution).

The dominance index (DI_i and DI'_i) are defined as the ratio between city i 's out-degree centrality and the average out-degree centrality of other cities:

$$DI_i^{(r)} = \frac{RC_i}{\frac{\sum_{j=1}^J RC_j}{J}} \quad (4)$$

where RC_i represents city- i 's out-degree centrality; and the RC_i in the rank size distribution is $\frac{1}{i}$.

Our result shows that there is a considerable polycentricity in the YRD ($PI = 0.7$), as this value is considerably higher than the PI of a rank size distribution ($PI' = 0.5$). This finding is consistent with other measurements of the YRD's polycentricity as presented in Liu et al. (2016) and Song (2014). Our result provides extra evidence of a polycentric YRD spatial organisation, and shows how Weibo data can be used for analyzing urban-geographical patterns.

3.5 Conclusions

Because of uneven geographies of data availability, research into the urban geographies of social media have tended to turn a blind eye to those places where 'mainstream' social media technologies are (made) unavailable, in spite of these regions having high Internet penetration rates and more (local) social media users. The aim of this study has been to assess the research potential of LBSM services in a Chinese context, by focusing a specific example: deriving intercity connections from Weibo. Our study thus contributes to the urban-geographical research on social media in three ways. First, the analysis shows how Weibo data can be used as a potential data source to assess spatial patterns. Second, we provide a method for generating intercity networks from social media data. And third, we confirm the 'round truth' of these data by exploring the spatial organisation of the YRD region as visible in people's day-to-day reproduction of the region.

In our study, the following intercity patterns emerged: (i) a small percentage of cities and city-dyads constitute the backbone of this urban network; (ii) the dominant direction of individual flows tends to be from primary cities to sub-primary cities, and from peripheral cities to primary cities; (iii) the distribution of city-dyad connectivities does not strictly follow nodal connectivities; (iv) the effects of administrative boundaries and cities' administrative level are significant; (v) and the YRD's polycentric structure becomes obvious through the lens of intercity people movements.

Spatially-embedded data generated from Weibo thus undoubtedly open up new avenues for further research. However, we should keep in mind that the geography generated from Weibo is the 'tale' of social media users. That is to say, the accuracy, and representativeness of such 'self-selected' data also needs to be analysed in the Chinese context – Weibo users are not a random sample from the population, and those using the LBSM features of Weibo are probably not a random sample of Weibo users. Testing the reliability of Weibo data in other regions in China and against other Internet users such as WeChat is therefore an obvious avenue for future research.

Notes

1. Alexa is an Internet information provider company, which provides global rankings and traffic data on websites.
2. As a general rule, the places of users' registration, which normally correspond to their hometown or permanent residence, always attract the most geo-tagging activities for every user. We therefore validate the reliability of user hometown by comparing the correlation of cities whole geo-tagged times and registered times as hometown. The result of correlation test (Pearson correlation coefficient = 0.93) verifies that the information on the places of users registrations is reliable.

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4. How sensitive are measures of polycentricity to the choice of ‘centres’? A methodological and empirical exploration

Zhang W. How sensitive are measures of polycentricity to the choice of ‘centres’? A methodological and empirical exploration. Working paper. ¹

Abstract

In the literature dealing with measuring polycentricity, relatively little attention has been paid to the choice of what constitutes a ‘centre’. In this paper, I assess the sensitivity of these measures to one particular aspect of this selection of the units of analysis: using the case of ‘polycentric urban regions’, I empirically examine the sensitivity of the ‘level’ of polycentricity to the number of cities included in the analysis. Based on a two-mode firm-city data source, I do so by stepwise measuring the polycentricity of the Yangtze River Delta (YRD) as cities are added to the analysis (i.e. measuring ‘stepwise polycentricity’). The result suggests that the measure of polycentricity is indeed highly sensitive to the choice of the number of cities. I propose that the analysis of the sensitivity of polycentricity can help researchers to (i) investigate the different role of cities in shaping polycentric structures of urban regions and (ii) identify mono- or poly-centric structures of urban regions. Analyses of the trend of the ‘stepwise polycentricity’ of the YRD and other seven urban regions along the Yangtze River Economic Belt serve to illustrate.

¹ I am pleased to acknowledge the work of my promoter, Professor Ben Derudder, who has commented and shaped various drafts of this chapter.

4.1 Introduction

‘Polycentric development’ has become a widely used term in urban research and urban policy narratives alike, as well as a normative goal in spatial planning. This has been especially the case since the ‘European Spatial Development Perspective (1999)’ was published, where polycentric development was set as one of three main guiding principles for European spatial development. The academic debate on polycentricity now spans multiple scales (intra-urban, inter-urban or regional, national; see McDonald and McMillen, 1990; Waterhout et al., 2005; Hall and Pain, 2006), adopts different perspectives (morphological versus functional polycentricity; see Burger and Meijers, 2012), and has branched off in several sub-literatures (e.g. theoretical explorations, empirical analyses, and assessments of its alleged social economic and environmental effects; see Hoyler et al., 2008; Meijers and Burger, 2010; Brezzi and Veneri, 2015). In spite of its increasing popularity, research on urban polycentricity is characterized by a number of seemingly perennial debates. For example, its theoretical rationale has been deemed elusive (Kloosterman and Musterd, 2001; Lambregts, 2009); there is no consensus about some basic definitions (Parr, 2004); results of empirical analyses strongly vary by measurement scheme (Green, 2007; Meijers, 2008); and possible economic implications have often been asserted without substantial evidence (Davoudi, 2003; Parr, 2004; see, however, Meijers and Burger, 2010).

In this paper, I focus on one element of the recurring methodological conundrum in the measurement of ‘urban polycentricity’: the question of what constitutes an ‘urban centre’. Although the conceptual and operational definition of a ‘centre’ is of paramount importance in any measurement exercise, its impact has not always been recognized. The issue of a proper definition of a ‘centre’ itself has many aspects, ranging from the territorial/scalar outline of centres (cf. Burger et al., 2008) to the question of how many centres should be included when formally assessing polycentricity (Meijers, 2008). In this paper, I specifically focus on the latter question using the example of ‘polycentric urban regions’ (PURs). PURs are generally defined as urbanized regions having a ‘relative balance’ between a set of important ‘urban centres’ within the region (Kloosterman and Musterd, 2001; Parr, 2004; Green, 2007; Lambregts, 2009; Burger and Meijers, 2012, Vasanen, 2013).

This does not necessarily mean that all cities within the region need to have a 'similar' size, as a PUR not only consist of a series of inter-connected large cities but also a range of medium-sized and smaller centres. When assessing the level of polycentricity in a putative PUR, without clear rationale on which and how many cities to include, the results of any exercise may risk to be shaped by the pre-hoc selection of centres. In other words, polycentricity may be sensitive to the choice of centres in quantitative analyses, and in this paper I seek to assess some of the key contours of this sensitivity.

The issue of identifying which settlements to include has been raised by Meijers (2008), who rightly argued that the choice of the threshold for inclusion of cities affects the subsequent measurements. As a response to this concern, Meijers proposed that a fixed number of cities should be adopted when assessing different PURs. Nonetheless, the concern of the sensitivity of polycentricity to the choice of cities has not received detailed attention in the literature. One possible reason is that PUR debates – which have mostly been articulated in (northwestern) Europe – are often linked to a series of small- and medium-sized cities of roughly equal importance (i.e. not following the logic of large city; see, Dijkstra, Garcilazo and McCann 2013). In this case, the effect of the choice of cities on measures of polycentricity may seem to be of secondary importance. For instance, according to Meijers and Sandberg (2008) in their measurement of the polycentricity of Germany, Sweden and Greece, results for selecting top 10 cities correlate strongly with results for selecting top 5 or 20 cities. However, this does not imply that this is a minor issue per se. Evidence can be found in the ESPON (European Spatial Planning Observation Network) measures of the polycentricity of EU countries (ESPON 1.1.1, 2006), which seems to produce a somewhat unconvincing result because of including many smaller centres (cf. Meijers, 2008). Moreover, there is a growing tendency to apply the concept of PURs in understanding urban regions in which there is a 'large city logic', including urban regions in China (e.g., Li and Phelps, 2016 a/b; Liu, Derudder and Wang, 2017; Song, 2014) and Latin American (Fernández-Maldonado et al. 2014). In these regions there is often a major gap between large cities and small cities in terms of their 'importance' (however measured). With regard to this, as Li and Phelps (2016a: 12) have noticed in the case

study of the Yangtze River Delta (YRD), the degree of ‘polycentricity (of the YRD) decreases as the sample size increases.’ In other words: in such cases adding many small cities into the measurement of polycentricity may strongly influence the ‘balance’ among the cities included in the analysis. As a result, successfully differentiating major urban centres, those that matter most for the level of polycentricity, and smaller centres can be assumed to be vital in measurement schemes.

Against this backdrop, this mostly methodological paper is intended to explore the sensitivity of polycentricity to the choice of cities. A first objective, therefore, is to examine how measures of polycentricity are subject to the choice of cities. In practice, I do this by stepwise measuring the polycentricity of an urban region as cities are added. The evolution of this ‘stepwise polycentricity (SP)’ may provide direct evidence of the sensitivity of polycentricity to the choice of cities.

The objective of this paper, however, is not limited to methodologically showing the sensitivity of polycentricity to the choice of cities. A second objective is to explore what I can ‘gain’ from an investigation of stepwise polycentricity (SP). As the SP measure quantifies the ‘balance’ among the major urban centres cities, the change of SP has the potential to uncover the roles each city plays in shaping a PUR. Furthermore, different structures of urban regions are assumed to exhibit different patterns of SP change. Varied patterns of SP change, in turn, has the potential to identifying mono- or poly-centric structures of urban regions. The second objective of this paper is thus to (i) investigate the role of cities in shaping regional formation and (ii) identify mono- or poly-centric structures of urban regions.

Our research is illustrated through an empirical analysis of the YRD, an archetypal mega-city region in China. Based on a bipartite network projection (Liu and Derudder, 2012) of a firm-city data source, I (re-)examine the polycentric structure of the YRD by applying SP measurements. Furthermore, to show the wider significance of the measure of SP for identifying different mono- or poly-centric structures of urban regions, I chart the changes of SP of seven further urban regions along the Yangtze River Economic Belt (YREB).

The remainder of this paper is organized as follows. The next section presents the approach to measuring SP, introduces the case study regions and describes the data. After that, I discuss the results of the empirical investigation, which is developed in three parts: I show and discuss the SP of the YRD, investigate the role of cities of the YRD in shaping its polycentric structure, and present a comparative analysis among other urban regions along the YREB. This is followed by the paper's conclusions.

4.2 Methods, case study regions, and data

4.2.1 Methods: measuring stepwise polycentricity (SP)

I propose a stepwise procedure to exhibit how the measure of polycentricity responds to the change of the number of cities that are added into analyses. This procedure consists of two simple steps: first, ranking the importance of cities; and second, stepwise measuring the polycentricity among the top n cities. In operational terms, I can apply any of the existing methods in the literature of quantifying polycentricity to rank the size of cities and measure their balance.

- Ranking the size of cities

In the literature on quantifying polycentricity, the size of cities can be defined in terms of (1) a morphological perspective, which is based on attribute features such as GDP and population (Spiekermann and Wegener, 2004; ESPON Monitoring Committee, 2007; Burgalassi, 2010); and (2) a functional perspective, which is based on the structure of linkages such as incoming and/or outgoing communication flows (Burgalassi, 2010; De Goei et al., 2010). Morphological measures and functional measures, however, are not incommensurable. Burger and Meijers (2012) propose a theoretical framework to link both approaches (also see the application in Liu, Derudder and Wu, 2016). Put simply, within the same network-based analytical framework, a city's morphological importance could be quantified in the proxy form of its total functional connections with all other cities within and outside the regional urban system (i.e. total centrality), while its functional importance is only related to its functional connections within the regional urban system (i.e. internal centrality) (for more details, see Burger and Meijers, 2012).

As urban polycentricity is often analysed from the both morphological and functional perspectives (e.g., Burger and Meijers, 2012; Hall and Pain, 2006; Green, 2007), to strengthen the comprehensiveness of the empirical investigation in this paper, I will contrast the sensitivity of morphological polycentricity and functional polycentricity. As a result, I employ Burger and Meijers's framework (2012) to define cities' size from both perspectives in a coherent manner. That is, based on the same urban network data, cities' total centrality is used to rank their morphological size, while cities' internal centrality is used to rank their functional size.

- Measuring 'balance' in city-size distributions

There are various methodologies developed for quantifying the 'balance' in city-size distributions, such as measuring the rank-size distribution of cities' size (Parr, 2004; ESPON Monitoring Committee, 2006; Burgalassi, 2010), evaluating the variance of cities' size (Hanssens et al., 2014), and benchmarking the distribution of cities' size through a comparison with some dummy or ideal-typical mono- or poly-centric distributions (Hanssens et al., 2014; Green, 2007) (for a detailed review with regard to this, see Liu et al. 2016).

In this paper, I adopt the method originally developed by Green (2007) and subsequently extended by Liu et al. (2016) to stepwise measure morphological and functional polycentricity. Green's method standardizes polycentric indicators through a comparison with a completely monocentric two-node network. Morphological polycentricity is calculated as:

$$P_M(n) = 1 - \sigma_m / \sigma_{mmax} \quad (1)$$

where:

$P_M(n)$ is the morphological polycentricity of an urban region by taking into account the top n cities, ranging from 0 (absolute monocentricity) to 1 (absolute polycentricity); σ_m is the standard deviation of cities' total centrality; σ_{mmax} is the standard deviation of nodes' total centrality of a two-node network where one node's total centrality equals 0, and the other's total centrality equals the highest total centrality in the city set N .

Functional polycentricity can be calculated as follows:

$$P_F(n) = (1 - \sigma_f / \sigma_{fmax}) \times \Delta \quad (2)$$

where $P_F(n)$ is the functional polycentricity of an urban region by taking into account the top n cities, ranging from 0 (absolute monocentricity) to 1 (absolute polycentricity); σ_f is the standard deviation of cities' internal centrality; σ_{fmax} is the standard deviation of nodes' internal centrality of a two-node network where one node's internal centrality equals 0 and the other's internal centrality equals the highest internal centrality in the city set N ; Δ is the network density of city set N , which is defined as the ratio of the total intercity connections to the maximum of intercity connections that is theoretically possible (see also Green, 2007; Liu et al., 2016).

4.2.2 Case study regions: YRD and other seven urban regions along the YREB

The YRD¹ comprises a series of physically separate but functionally (unevenly) interconnected cities. It consists of multiple economic, demographic and political cores: four economic centres with a GDP of over 500 billion RMB (i.e. Shanghai, Nanjing, Hangzhou, and Suzhou); three demographic cores with a population of over five million (i.e. Shanghai, Nanjing and Hangzhou); and, politically speaking, one municipality directly under the central government (Shanghai) and three sub-provincial cities (Nanjing, Hangzhou and Ningbo). These cities are strongly interlinked through dense motorway and high-speed railway networks, which provide extensive labour markets and foster deeper regional integration (Chen, 2012). Furthermore, the inequality in the distribution of cities' size such as GDP and population within the YRD is remarkable (Figure 4.1). The region's polycentricity has repeatedly been verified in the literature (Song 2014; Liu et al., 2016; Li and Phelps, 2016 a/b; Zhang et al., 2016). Here, I re-assess its polycentric structure using the stepwise measure.

To show how the sensitivity analysis can help to identify mono- or poly-centric structures of urban regions, I assess the changes of SP of other seven urban regions along the YREB. The YREB – a subnational territorial unit which covers 11 province-level administrative units with more than 40% national population – has

been one of the two components of China's great T-shaped territorial development strategy (the other is the coastal economic belt). This region accommodates various urban regions: apart from the YRD, other urban regions are the Wanjiang cluster, the Changsha-Zhuzhou-Xiangtan cluster, the Wuhan cluster, the Poyang Lake cluster, the Chongqing-Chengdu cluster, the Central Yunnan cluster and the Central Guizhou cluster (Figure 4.2). Their definitions draw upon Fang et al.'s (2010) identification, which has been acknowledged by central governmental agencies. The typology of these YREB urban regions varies immensely in terms of the number of cities, area, and degree of polycentric development (according to Liu et al. 2016), which offers a good sample to presents different (mono-/poly-)centric patterns of urban regions.

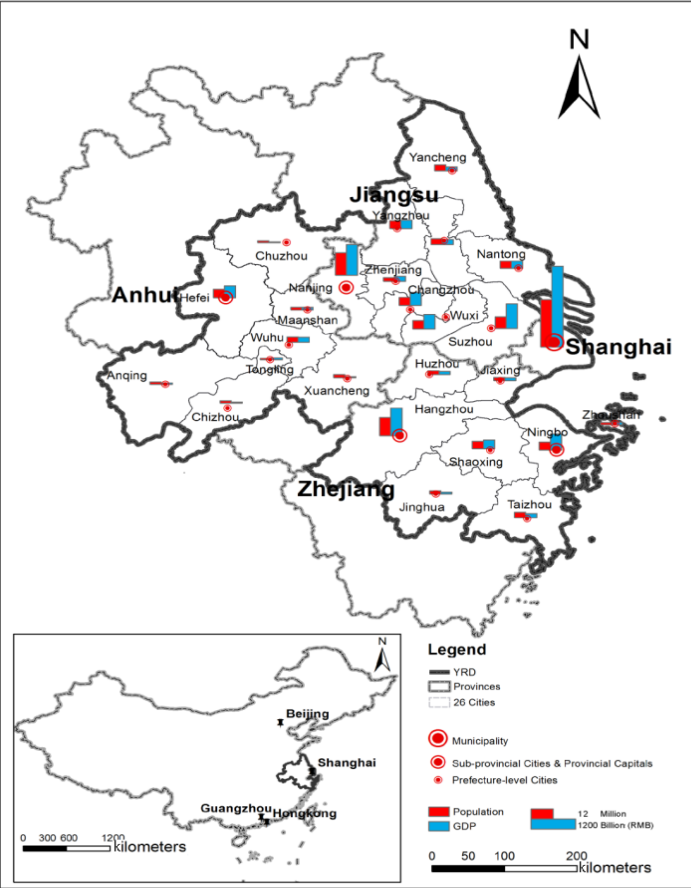


Figure 4.1. The Yangtze River Delta with its GDP and demographic distribution

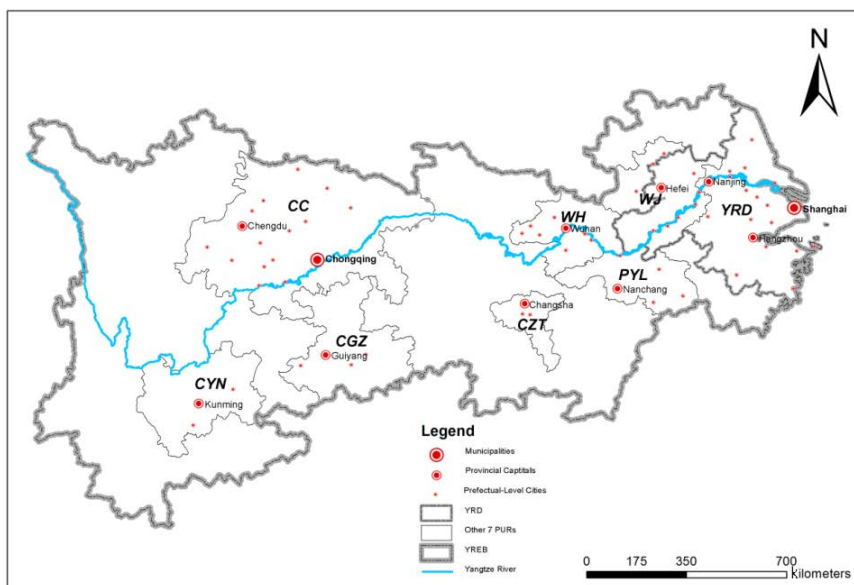


Figure 4.2. Eight urban regions along the Yangtze River Economic Belt

(YRD = Yangtze River Delta; WJ = Wanjiang cluster; CZT = Changsha-Zhuzhou-Xiangtan cluster; WH = Wuhan cluster; PYL = Poyang Lake cluster; CC= Chongqing-Chengdu cluster; CYN = Central Yunnan cluster; CGZ = Central Guizhou cluster)

4.2.3 Data collection and processing

There is a growing body of literature on measuring intercity connections, including through infrastructural linkages (e.g. Liu et al., 2016), proxy measures of intercity workflows through advanced service functions (e.g. Taylor and Derudder, 2016), corporate command relations (e.g. Alderson et al., 2010), knowledge collaboration (e.g. Li and Phelps, 2016a/b) and commuting interactions (e.g. Vasanen, 2013). In this research, I employ the proxy based upon the location strategies of business services firms. To this end, I implement the interlocking network model (INM) devised by the Globalisation and World Cities (GaWC) research group (Taylor, 2001; Taylor and Derudder, 2016) to infer city-city networks from a Chinese firm-city database. The rationale behind the INM is that the office networks of producer services (PS) firms connect the cities in which they are located. Based on the co-

presence of office networks of service firms between two cities, the connectivity of city-dyads can be calculated. Given the multiplexity of urban networks, I emphasise that this approach simply represents but one example of intercity linkages (Burger, van der Knaap and Wall, 2014).

The formal specification of INM is presented in Taylor and Derudder (2016); below, I restrict ourselves to the basics of data gathering and processing. The operationalisation of INM starts with collecting data on the location matrix of m PS firms in n cities. This in practice includes the selection of firms and cities and the assignment of service values.

- Firstly, the selection of firms was based on the sectoral ranking for 2013. A total of 247 firms were identified in eight sectors: 50 accountancy firms, 41 advertising firms, 23 management consultancy firms, 35 law firms, 21 bank firms, 26 insurance firms, 30 security firms and 21 trust firms².
- As PS firms mainly set their branches in cities rather than towns, the city list has been restricted to all 289 cities at prefecture level and above in Mainland China (source: based on China City Statistical Yearbook 2013). The end product thus is a 247 PS firms \times 289 cities matrix.
- The websites of these 247 PS firms provide information about the size of their presences (e.g. the number of practitioners) and their extra-locational functions (e.g. national headquarters and regional headquarters) in these 289 cities. In line with GaWC research, I encode the two types of information into standardized service values according to a six-point scale, with values ranging from 0 (no presence) to 5 (headquarter).

From the city-by-firm service values matrix, the city-dyad connectivity CDC_{a-b} between cities a and b is defined as follows:

$$CDC_{a-b} = \sum_{j=1}^{247} V_{aj} \times V_{bj} \quad (3)$$

where V_{ij} ($i = a, b$) is the ‘service value’ of city i to firm j .

The total centrality and internal centrality of the city a are therefore computed by:

$$Total\ Centrality(a) = \sum_{i=1}^{289} CDC_{a-i} \quad (4)$$

$$Internal\ Centraliity(a) = \sum_{j=1}^{m-1} CDC_{a-j} \quad (5)$$

where i refers all cities within and outside the urban region that city a is located in, which is limited to all 289 prefecture level and above cities in mainland China; j refers to the cities within the same urban region that city a is located in; and m refers to the number of the cities within each of the urban regions.

4.3 Results and discussions

4.3.1 Stepwise Polycentricity (SP) of the YRD

The result of the stepwise measurement for the YRD is shown on a scatter diagram with trend lines (Figure 4.3). An initial observation is that the SP – in both the morphological and the functional sense – has a relatively high value when Shanghai, Nanjing, and Hangzhou have been stepwise added into the analysis, after which there is a significant drop-off – particularly in functional polycentricity – when more cities such as Hefei, Ningbo and Suzhou are added into the consideration. This clearly shows that the measure of polycentricity is indeed contingent on the number of cities. But the key finding here is that the drop-off is rather steep, which implies the large differentiation between the three main centres and the other cities in shaping the polycentric structure of the YRD.

Second, the disparity in the trend lines of morphological and functional SP is noteworthy. Recall that the morphological measure is based on the total (extra-regional and intra-regional) intercity linkages, while the functional measure is only based on intra-regional intercity linkages. This shows that the importance of the YRD's cities as a provider for regional and national functions is more balanced than that as a provider for regional functions within the YRD. However, the approach to measuring functional polycentricity, which adds the component of network density, also partly results in rather low functional polycentricity compared to other measures (Song, 2014; Li and Phelps, 2016b; Zhang et al., 2016). But, the result itself, in turn, reflects the quite weak density of intra-regional business connections when taking more cities into consideration.

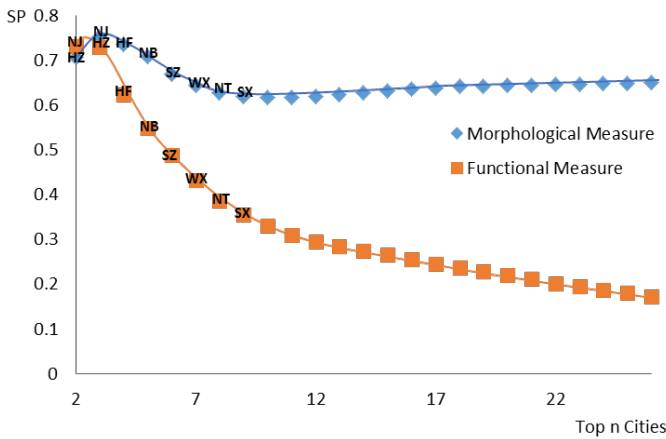


Figure 4.3. Stepwise polycentricity of the YRD

(NJ=Nanjing; HZ=Hangzhou; HF=Hefei; NB= Ningbo; SZ=Suzhou; WX=Wuxi; NT=Nantong; SX=Shaoxing; the tags of each point represent newly added cities)

4.3.2 Different role of cities of the YRD in shaping its polycentric structure

Discussing the different role of cities of the YRD in shaping its polycentric structure is an exercise that is closely related to the change in SP as shown above. First, the ‘turning points’ between the relatively high values of SP and the obvious ‘drop-offs’ in the both curves point to Shanghai, Nanjing, and Hangzhou producing a maximally balanced regional urban system. This seems to be a straightforward conclusion but can be recast into a broader argument: the three cities are the three main centres within the poly-centric urban regions. This is consistent with not only other scholars’ observations (Hall, 1999; Li and Phelps, 2016a; Liu et al., 2016) but also official definitions of the multiple centres of the YRD. In the YRD agglomeration development plan recently approved by the State Council of China, Shanghai, Nanjing and Hangzhou are positioned explicitly as regional main centres: Shanghai is assigned to play the function of ‘global city’, with emphasis on housing producer services and undertaking the role of a financial and innovation centre; Nanjing is assigned to perform the function of regional financial, business services, and educational centre; and Hangzhou is also designed to one of the economic centres of the YRD, with the focus on cultural creative industries and e-commerce. Second, the

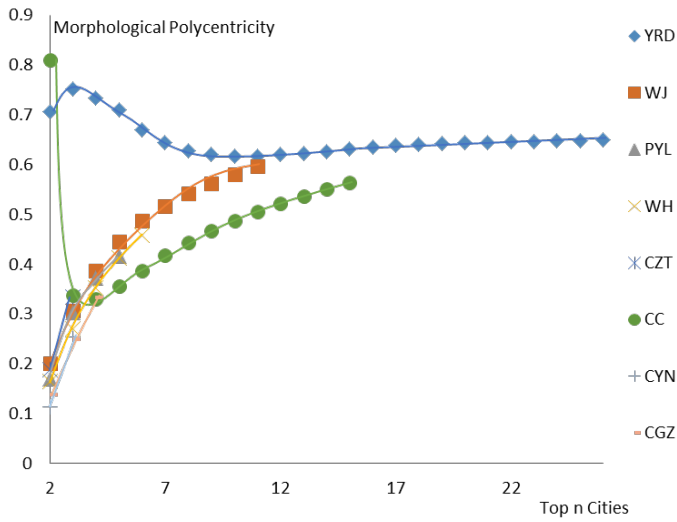
obvious ‘drop-off’ in the measure of SP implies that adding other cities considerably changes the assumed ‘balance’ among the three primary cities. As a corollary, these cities matter less for shaping the polycentric structure of the YRD. Thus I can conclude that the YRD can be best understood as a three-centric urban system with more peripheral cities that affect the regional formation to a lesser extent, and the uneven pattern of cities’ importance is more visible from the functional perspective.

4.3.3 Investigating mono- or poly-centric structures of urban regions along the YREB

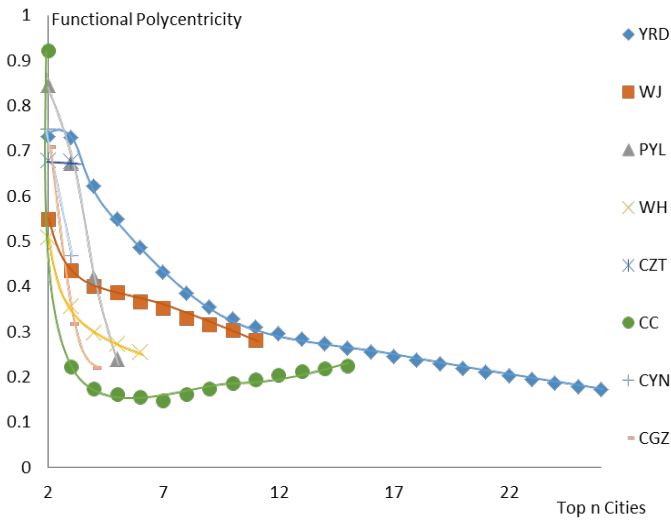
In this section, I measure the SP of the other seven urban regions along the YREB from the both morphological and functional perspectives. Figure 4.4 charts their change patterns, which can be classified into three meta-types.

- The SP of most of these urban regions from a morphological perspective, with the exception of the YRD and the Chongqing-Chengdu cluster, are representative for the first type. Their SP starts from a low initial value and then gradually increases when more cities are added. This implies that the largest city and the second largest city have a weak balance, while the addition of more cities increase the ‘balance’ between the top two cities. Clearly, this trend defines a monocentric structure.
- The second type is visible in the Changsha-Zhuzhou-Xiangtan cluster in its functional polycentricity. Its functional SP starts from a high initial value and then fluctuates around the initial value when more cities are added. This trend means that all cities share a relatively high balance with the primary city. This, of course, points to a polycentric structure, but with a particular pattern in that all cities have a roughly similar size.
- I can abstract the third meta-type of the change of SP from the remaining patterns. Similar to the pattern of the YRD, their SP starts from a high initial value and also has a significant drop-off when more cities are added. As discussed before, this trend points to a polycentric structure.

Table 4.1 lists the three meta-types of the trend of SP and maps corresponding topologies of regional structures.



a: Morphological Polycentricity

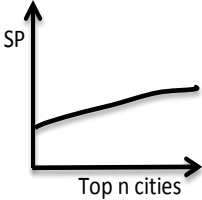
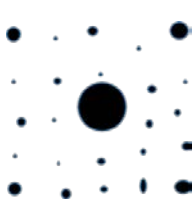
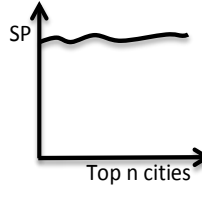
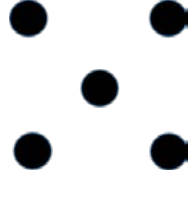
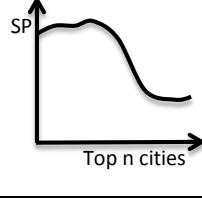
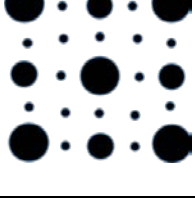


b: Functional Polycentricity

Figure 4.4. Stepwise polycentricity of eight major urban regions along the YREB

(YRD = Yangtze River Delta; WJ = Wanjiang cluster; CZT = Changsha-Zhuzhou-Xiangtan cluster; WH = Wuhan cluster; PYL = Poyang Lake cluster; CC= Chongqing-Chengdu cluster; CYN = Central Yunnan cluster; CGZ = Central Guizhou cluster)

Table 4.1. Typologies of eight urban regions, trends of stepwise polycentricity, and topologies

Patterns	Examples		Trends of stepwise polycentricity	Topologies of regional structures
	Morphological perspective	Functional perspective		
Monocentric urban regions	WJ; PYL; WH; CZT; CYN; CGZ			
Polycentric urban regions that consist of cities with similar size		CZT		
Polycentric urban regions that consist of large and small cities	YRD; CC	YRD; WJ; PYL; WH; CC; CYN; CGZ		

(YRD = Yangtze River Delta; WJ = Wanjiang cluster; CZT = Changsha-Zhuzhou-Xiangtan cluster; WH = Wuhan cluster; PYL = Poyang Lake cluster; CC= Chongqing-Chengdu cluster; CYN = Central Yunnan cluster; CGZ = Central Guizhou cluster)

I am now in a position to explain how the mono- or poly-centric patterns in the regions are reflective of the intuitive impression of their regional structures. In morphological terms, all these monocentric urban regions are dominated by provincial capitals. This is in line with the strong political undercurrents in the Chinese urban system (Cartier, 2016). In the context of decentralisation of China's urban government (Wei, 2001), cities' administrative levels (such as municipality-

level, sub-provincial level, and prefectural level) to some extent represents policy-making power. And the policy-making power is closely related to free(r) market policies and statutes, which is a crucial factor for attracting service firms' access. As a result, high political-level cities such as municipalities and provincial capitals are more likely to be preferred cities when service firms are expanding their office networks, and more easily play the role of gateway cities to export services within and beyond provincial markets.

In the Chongqing-Chengdu cluster, the pattern of two nuclei is quite obvious: they have been deemed the twin poles of economic growth in the Western China. Obtaining official approval from the central government is an important signal for confirming a city's central position in regional/national urban systems in China. The Ministry of Housing and Urban-Rural Development (MHURD) of China recently proposed the concept of 'National Central Cities (NCCs)', through which the central government intend to reduce the burden of Beijing and Shanghai of accommodating massive flowing population and promote the development of these NCCs' surrounding. The connotation of NCCs is consistent with the definition of cities' morphological importance in this research, which focuses on cities' overall functions of servicing other cities within and beyond the urban regions they are located in. A couple of cities have been officially/quasi-officially acknowledged to be NCCs, including Beijing, Tianjin, Shanghai, Chongqing, Guangzhou, Shenzhen, Chengdu, Wuhan and Zhengzhou, while Chongqing and Chengdu are the only two NCCs within the same urban region. This, in turn, reflects that most urban regions are monocentric from a morphological perspective, with some exceptions such as the YRD and the CC.

In functional terms, the Changsha-Zhuzhou-Xiangtan cluster is special because all three cities are highly balanced. This is in line with the characteristics of this urban region: it only consists of three cities within a close geographical distance (30-minute commuting time), as well as being orchestrated as a tightly integrated alliance by local governments almost 50 years ago (Tao, 2005). Other urban regions all have two or three large cities, which function as regional growth poles within provinces or urban regions. An obvious example is the Poyang Lake cluster, which has a conspicuous dual-nuclei functional structure that has been tightly connected by

the well-developed Nanchang-Jiujiang (*Chang-jiu*) industrial corridor with plenty of government-dominated investments (Waters, 1997).

4.4 Conclusions

In this paper, I revisited the issue of the sensitivity of the ‘level’ of polycentricity to the number of cities included in the analysis. I did so by performing a stepwise measurement of the level of polycentricity in the YRD and other seven urban regions, drawing on intercity business connections in China. The empirical investigation clearly shows that measures of polycentricity are highly sensitive to the choice of cities. As this research is built upon the example of urban regions with large city logic, the significant difference between large cities and small cities in terms of city size in these regions may magnify the sensitivity of polycentricity to the choice of cities. However, this does identify a need for analyzing which cities matter most for determining polycentricity when assessing polycentric urban regions. Without such an analysis, any measure of polycentricity will risk to be shaped by choice of cities.

Our analysis also shows the additional potential uses of the sensitivity investigation of polycentricity. First, drawing on the examples of the YRD to illustrate, the trend of SP can be used to investigate the different roles cities function in shaping regional structures. Second, the change curves of SP can also serve to identify mono- or polycentric structures of urban regions. Based on the examples of seven urban regions along the YREB, I abstract three meta-types of change of SP.

As a methodological and empirical exploration, this paper has a couple of limitations, which simultaneously suggest avenues for further research. The first concerns how the units of analysis are defined. The selection of the number of cities cannot be explored independently from the issue of what constitutes a city, especially not in areas where urbanisation is nebular and centre identification becomes an issue in its own right. Although this paper is set up as a specific exploration on the basic question of the number of cities when assessing urban polycentricity, discussing a broader question of unit selection would be an obvious area for future research. Second, the question as to which cities should be included in practice has remained unanswered. For instance, because the ‘turning point’ in the measure of SP allows

identifying the most ‘important’ cities in shaping polycentric structures, here it is viewed as a meaningful indicator to quantify the extent of polycentricity. This, however, requires further theoretical and empirical verification. The point I argue here is that, in any case, the selection of cities when assessing polycentric urban regions should be on the basis of the investigation of the sensitivity of polycentricity.

Notes

1. Since the YRD has various boundaries according to different definitions, in this research, I follow the official delineation presented in the YRD agglomeration development plan, which was recently approved by the State Council of China. This produces 26 cities, which spread over Jiangsu, Zhejiang and Anhui Provinces and the municipality of Shanghai.

2. The initial list of firms included the top 50 accounting firms (source: goo.gl/TDDy9p; published July 2013), the top 50 advertising firms (source: goo.gl/37FERZ; published September 2013), the top 50 management consultancy firms (source: goo.gl/v43XI5; published August 2013), the 35 law firms (including the top 20 largest domestic law firms and the top 15 international law firms; source: goo.gl/OsCspB; published December 2013), the 21 main nationwide banks (source: goo.gl/fwHRMr; accessed at December 2013), the top 30 insurance firms (source: goo.gl/2z7oW9; accessed at December 2013), the 30 largest security firms (source: goo.gl/gcFhg8; accessed at December 2013), and the 30 largest trust firms (source: goo.gl/Pvn2Zh; accessed at December 2013) in Mainland China. As the websites of some of these firms did not offer information on where major service firms are located during the actual data collection, the end list of firms only includes 247 effective firms.

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5. An analysis of the determinants of the multiplex urban networks in the Yangtze River Delta

Zhang W, Derudder B, Wang J and Witlox F. (2017) An analysis of the determinants of the multiplex urban networks in the Yangtze River Delta. *Submitted for possible publication to Tijdschrift voor Economische en Sociale Geografie.*

Abstract

This paper examines the different determinants of three types of urban networks within the Yangtze River Delta (YRD). The three urban networks are built based on transport infrastructure links, business interactions in producer services (PS) firms and leisure mobility. The influence of distance, size (GDP and population), administrative borders, landform contiguity, cultural affinities, economic alliances and administrative rank are examined. The results obtained from network correlation and network regression show that only some of these explanatory factors decisively affect each of the three networks, in spite of significant correlations between all of these explanatory factors and the three urban networks. Empirical results highlight the reasons for the different structures of the three types of urban networks, and enhance our understanding of the YRD's regional formation.

5.1 Introduction

Urban networks are multiplex phenomena. Urban network organisations can be represented in different forms, depending on the particular lens through which these are viewed (Burger et al., 2014). When cast in terms of Castells’ (1996) typology of different ‘spaces of flows’, multiplex linkages between cities can be understood as a combination of three layers: infrastructure connections, flows of social practices and functions, and corporeal movements. Each network layer can, in turn, take different forms: the infrastructure layer can take the form of the Internet backbone, airline networks, maritime networks and high-speed railway networks; the social practices layer can take the form of business communications, exchanges of knowledge and capital flows; and the corporeal movements layer can take the form of shopping trips, business travel, leisure travel and even commuting of different age groups. Table 5.1 lists the main types of intercity linkages that have been explored in the urban network literature.

Table 5.1. Multiple types of intercity linkages that have been explored in the urban network literature

Types of intercity linkages	Examples
Corporate command relations	Alderson et al. (2010)
Potential workflows within advanced producer service firms	Taylor and Derudder (2016)
Knowledge exchange	Li and Phelps (2016 a/b)
Internet backbone bandwidth	Townsend (2001)
Air travel links	Smith and Timberlake (2001)
Maritime transport	Ducruet and Notteboom (2012)
Telecommunication flows	Krings et al. (2009)
Transport infrastructure links	Liu et al. (2016)
Commuting flows	De Goei et al. (2010)
E-commerce transactions	Xi and Zhen (2017)
Mobility based on location-based social media tagging	Zhang et al. (2016)

Adding to this diversity, urban networks have been mapped across different geographical scales (Neal, 2013), ranging from local (Liu et al., 2012) and regional (Hall and Pain, 2006), to national (Zhao et al., 2015) and global (Taylor et al., 2012). Burger et al. (2014) describe the presence of multiple linkages as ‘the multiplexity

of urban networks' and advance three main arguments in this respect. First, different types of functional linkages do not necessarily have the same spatial structure and geographical scope, despite their interconnectedness. Second, cities play different roles in different types of functional linkages. And third, the multiplexity of urban networks is also related to the multiscale nature of urban networks, in that a change of functional linkages on a particular geographical scale will affect other functional linkages on other geographical scales. Although the multiplexity of urban networks has been widely recognized (Lambregts, et al. 2005; Davoudi, 2008; Burger et al., 2014), empirical studies examining the relationships between different networks are relatively sparse. Studies that do tackle the question of the similarities and differences between different networks include comparisons between Internet backbone and air transport intercity linkages (Choi et al., 2006), worldwide air and sea flows (Ducruet et al., 2011), global airline networks and global service connectivities (Taylor et al., 2007), business travel, shopping and the commuting of highly educated and less-educated segments of the workforce (Burger et al., 2014). Similarly, Liu et al. (2013) explore the co-evolution of airline networks and corporate networks, while Lao et al. (2016) compare China's airline networks and economic networks, in which the spatial patterns of different networks share some commonalities, but also present specific formations.

In this research, we tackle a hitherto unaddressed question with regard to the multiplexity of urban networks: the first objective of this paper is to analyse the different drivers underlying the variegated geographical outline of these different networks. In the domain of modelling urban networks, various driving forces that underlie network formation, such as gravity-type parameters (i.e. distance and city size (Black, 1972; Krings et al., 2009)), border effects, and political factors, have been applied. However, these modelling exercises have not explored whether these determinants affect each of the multiplex networks differently. To address this question, in this paper we explore and compare the determinants underlying three different urban networks in a single mega-city region, the Yangtze River Delta (YRD) in China.

The three types of intercity connections are integrated transport infrastructure links that include train and bus links, business interactions based on the location strategies

of producer services (PS) firms, and leisure mobility derived from geo-tagged social media posts. The reason for choosing these particular networks is that they represent three of the layers in Castells' (1996) typology of space of flows. Based on a literature review of the potential determinants of urban networks (e.g. Tobler, 1970; Krings et al., 2009; Black, 1972; Zhang et al., 2017), we include eight explanatory factors: distance, GDP, population, administrative borders, landform contiguity, cultural affinities, economic alliances and administrative rank.

To explore how the formation of the three networks varies as a function of these explanatory factors, we employ a network correlation and network regression analysis framework (Krackhardt, 1988). Because traditional statistical approaches fail to deal with interdependent observations in network data, standard inferential techniques are inappropriate for our purposes. We therefore perform a quadratic assignment procedure (QAP) (Borgatti et al., 2002) to (i) investigate the correlation between these explanatory factors and the three networks and (ii) examine how these explanatory factors affect the structures of each of these urban networks.

A second, related objective of this paper is to contribute to our understanding of the regional formation of the YRD (and other Chinese mega-city regions in general). China's mega-city regions such as the YRD and the Pearl River Delta (PRD) have been seen as prime examples of mega-city regions (Hall, 2009) and their near analogues such as global city-regions (Scott, 2001). Although the rise of Chinese mega-city regions seems to echo the 'new city-regionalism' in advanced capitalist economies, there are some contextual characteristics such as the strong political undercurrents in the spatial economic system (Cartier, 2015) and large city logic (Dijkstra et al., 2013), which may shape spatial organisation of Chinese mega-city regions in particular directions. However, investigations of their regional formation are rather thin on the ground. Some notable exceptions include Li and Phelps (2016 a/b), Zhang (with Kloosterman, 2016; 2017), Liu et al. (2016), Yang et al. (2017) and Zhao et al. (2017), in which researchers document the networked and polycentric formations of the YRD and PRD. This paper aims to enrich the literature on China's mega-city regions, with a particular focus on investigating which factors drive the regional formation of the YRD.

The remainder of this paper is organized into four sections. In the next section, we establish the three networks and briefly compare their similarities and differences in terms of city connectivities, city-dyad connectivities and network structures. After that, we discuss the potential explanatory factors, followed by a specification of our models. We then discuss the results of the correlation and regression analysis, after which the paper is concluded with a summary of our main findings.

5.2 Three urban networks connecting the YRD

In this paper, the YRD is taken to include all 41 cities at the prefecture-level and above in the Jiangsu, Zhejiang and Anhui provinces, in addition to the municipality of Shanghai. The YRD has been one of the three major engines of China's economic growth (the other two being the Beijing-Tianjin-Hebei urban region and the Pearl River Delta). Since the opening of the Pudong New Area in Shanghai in the 1990s, a series of central cities within the YRD (such as Nanjing, Hangzhou, Hefei, Suzhou and Ningbo) have experienced a rapid population and economic growth. In the process, substantial economic and human mobility networks have formed, as well as a series of comprehensive transportation corridors.

We focus on three networks within the YRD: a network of transport infrastructure links, a network of business interactions in PS firms, and a network of leisure mobility. The way in which these networks are constructed have been discussed in detail in other studies: the operationalisation of constructing the integrated transport infrastructure was devised in Derudder et al. (2014); the formal specification of the business network in PS firms was presented in Taylor and Derudder (2016); and the approach to deriving leisure mobility from geo-tagged social media posts was presented in Zhang et al. (2017). Here, we apply these approaches to devise three 41×41 cities networks interconnecting the YRD. Given space constraints, we restrict ourselves to a discussion of the basic steps of constructing these networks and an overview of the basics of the data gathering and processing. Readers are referred to the original papers for operational details.

- Integrated transport network

The transport infrastructure network is constructed as a composite network of bus and rail connectivity provisions, which are two major means of transporting people

within urban regions in general and the YRD in particular¹. The strength of bus and rail links is measured through the number of daily direct trains and buses between two cities. Train and bus schedules were crawled from an online bus schedule search engine (<http://www.piaojia.cn>) and the national train ticketing website (www.12306.cn), respectively. The bus data were also cross-referenced with other databases, such as www.checi.cn. All data were collected in the first week of January 2017. The two individual networks are treated as two symmetrical networks by averaging the dyad values between two cities. After this, we normalized the two datasets by using the min-max normalisation, so that they have a consistent distribution between 0 (minimum connectivity) and 1 (maximum connectivity). The integrated network was generated by adding together the two networks in an equal weight. That is, a city dyad's connectivity (i.e. the strength of intercity connections) in the integrated network is equal to the sum of its connectivities in each of the two networks.

- Business network in PS firms

Producer services (PS) firms organise their work and broaden their catchment area by setting up offices in different cities. The location strategies of PS firms can thus be used to approximate intra-firm knowledge flows across cities. The Globalisation and World Cities (GaWC) research group devised an interlocking network model (INM) to calculate the connectivities of city-dyads, based on the co-presence of PS firms in cities (Taylor, 2001). In practice, the operationalisation of the INM requires the selection of firms and cities, and the assignment of service values. The final product is a location matrix of m PS firms in n cities. For the selection of Chinese PS firms, we used sectoral rankings for 2013 for eight sectors: accountancy, advertising, management consultancy, law, banking, insurance, security and trust². A total of 247 firms were identified: 50 accountancy firms, 41 advertising firms, 23 management consultancy firms, 35 law firms, 21 banking firms, 26 insurance firms, 30 security firms and 21 trust firms. Obviously, our city list has been restricted to the 41 cities within the YRD. In line with the assignment rule of service values in the GaWC research, we coded the importance of a given city in a given firm's office network on the basis of the firm's size (e.g. the number of practitioners in law firms) and the

extra-locational functions (e.g. headquarter functions). A 6-point scale is used, with values ranging from 0 (no presence) to 5 (headquarter).

Based on the city-by-firm service values matrix, the strength of business linkages BL_{a-b} between cities a and b can be calculated as follows:

$$BL_{a-b} = \sum_j V_{aj} \times V_{bj} \quad (1)$$

(where V_{aj} , V_{bj} are the ‘service value’ of cities a and b to firm j)

- Leisure mobility network

Fine-grained data on human mobility is difficult to obtain in China. However, location-based social media provides an opportunity to capture these large volumes of individual mobility information. Here, information on intercity mobility is derived from Weibo, the major online social networking and microblogging service in China. Weibo users can share their location through a ‘geo-tagged’ service. Zhang et al. (2017) have proposed a method of deriving the data on intercity travel from Weibo users’ successive multi-tags information in different cities, and this is what we have replicated in this research. Using Weibo’s public application programming interface (API), we gathered 53.52 million geo-tagged records submitted by 7.03 million users within the YRD between January 2014 and November 2014. These records provide the temporal and spatial (geographic coordinates) information associated with geo-tagging. We connect individual successive geo-tagged cities within a 48 hour period as an effective intercity trip record. For instance, if a user posts two geo-tagged messages in cities a and b on 7th and 8th May, respectively, we assume that a trip occurred from city a to city b . When applying this transformation rule to our dataset, 0.54 million records of intercity trips between the 41 cities were generated. Previous studies have suggested that social media check-ins are skewed towards leisure and tourism activities (e.g. Liu et al., 2014). We therefore term the mobility network derived from the Weibo records as a leisure mobility network.

To facilitate comparison, for each city and city-dyad, we normalized their connectivities in each of the networks by using the min-max normalisation. Figure 5.1 maps the three networks, in which intercity connections are shown in various colours using a grey scale. The thickness of the edges also indicates the strength of

the intercity connections, and node sizes represent the cities' connectivities (i.e. the sum of the cities' connections). A comprehensive discussion of each city and city-dyad's position in each of the networks is obviously beyond the scope of this paper. Here we only show the top 10 cities and city-dyads, with regards to their connectivities, to briefly compare the three networks (Table 5.2). Additionally, we also map the rank-size distributions of the cities and city-dyads' connectivities to show some of the structural differences between the three networks (Figure 5.2). Four major observations can be made:

- When investigating the transport infrastructure network, three points stand out. First, as shown in Figure 5.1, the strongest connections are, above all, between neighbouring cities. Indeed, six of the top ten city-dyads are spatially contiguous, and the others are also only a short distance away. Second, the barrier effect of provincial borders seems significant: only one of the top ten city-dyads (Shanghai-Suzhou) crosses a provincial boundary. Moreover, the connectivity of Suzhou stands out, which is clearly related to its geographically central position in the northern part of the YRD.
- The most evident pattern in the business network is that the four provincial capital cities, i.e. Shanghai, Nanjing, Hangzhou and Hefei, are intensely interconnected, thus suggesting the importance of economic size and political power in shaping business relations. Meanwhile, Ningbo, another sub-provincial city and important economic centre, is also strongly connected to these four capital cities.
- The backbone of the leisure mobility network is constituted by the connections between Shanghai and its surrounding cities, such as Suzhou, Hangzhou and Huzhou. These surrounding cities all have well-developed tourism resources and thus play the role of 'backyard gardens' for the Shanghai residents. Furthermore, the spatial contiguity and the effect of provincial borders are also clearly visible in the top 10 most connected city-dyads.
- The difference in the structure between the three networks is obvious. Despite sharing features of power-law distribution of cities and city-dyads' connectivities, the transport infrastructure network is a relatively 'flatter'

network, while the leisure mobility network shows the steepest drop-off. One possible reason is that the development of transport infrastructure linkages is primarily devised by the political authorities, who need to consider not only accessing larger services and/or labour markets, but also promoting regional coordination. This is more apparent in China, in which the narrowing of regional gaps has been one of the primary targets of multi-level governments (Fan, 1997; Wu, 2015). In other words, the infrastructure linkages tend to reflect the ‘supply’ that enables intercity connections. The leisure mobility and business linkages, however, tend to reflect the actual ‘demands’ of intercity connections.

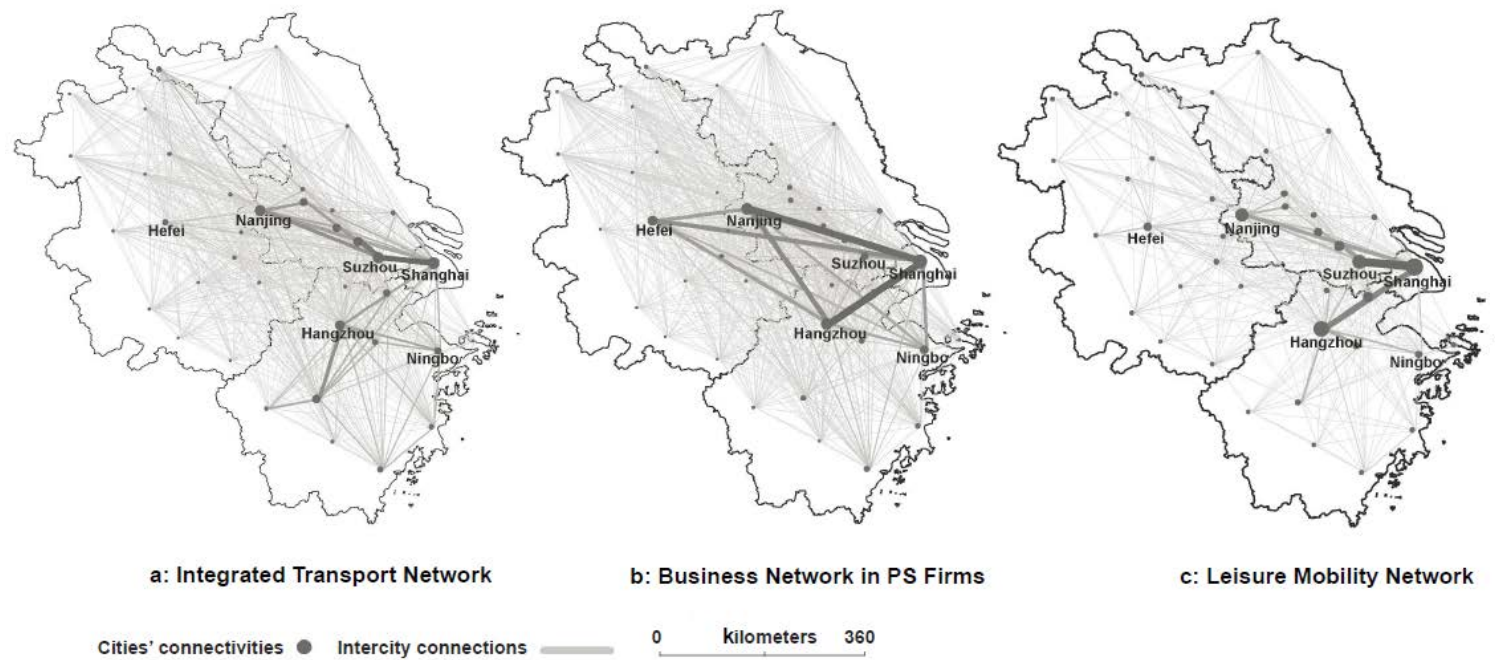


Figure 5.1. Three urban networks connecting the YRD

Table 5.2. Ten most connected cities and city-dyads in the three networks

Rank	City			City-dyad		
	Integrated transport network	Business network in PS firms	Leisure mobility network	Integrated transport network	Business network in PS firms	Leisure mobility network
1	Shanghai	Shanghai	Shanghai	Shanghai-Suzhou	Shanghai-Hangzhou	Shanghai-Suzhou
2	Suzhou	Nanjing	Hangzhou	Suzhou-Wuxi	Shanghai-Nanjing	Hangzhou-Jiaxing
3	Nanjing	Hangzhou	Suzhou	Nanjing-Suzhou	Nanjing-Hangzhou	Shanghai-Hangzhou
4	Wuxi	Hefei	Nanjing	Hangzhou-Jinhua	Shanghai-Hefei	Shanghai-Jiaxing
5	Hangzhou	Ningbo	Jiaxing	Nanjing-Zhenjiang	Shanghai-Ningbo	Suzhou-Wuxi
6	Jinhua	Suzhou	Wuxi	Hangzhou-Jiaxing	Nanjing-Hefei	Hangzhou-Shaoxing
7	Changzhou	Wuxi	Hefei	Suzhou-Changzhou	Hangzhou-Hefei	Shanghai-Nanjing
8	Zhenjiang	Wenzhou	Changzhou	Wuxi-Changzhou	Nanjing-Ningbo	Wuxi-Changzhou
9	Ningbo	Nantong	Ningbo	Suzhou-Zhenjiang	Hangzhou-Ningbo	Nanjing-Suzhou
10	Jiaxing	Shaoxing	Shaoxing	Nanjing-Wuxi	Shanghai-Suzhou	Nanjing-Zhenjiang

These conclusions, drawn from preliminary observations, are, of course, idiosyncratic and fragmented. In the next section we will systematically investigate the potential determinants underlying the different network formations through an analysis of network correlation and network regression.

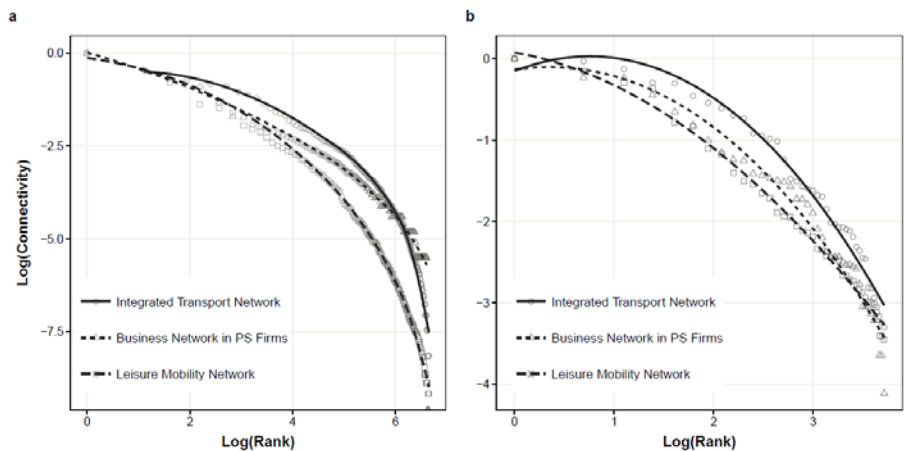


Figure 5.2. Rank-size distributions of connectivities of city-dyads (a) and cities (b) in the three networks

5.3 Model specification

5.3.1 Selections of explanatory variables

In this research, eight potential factors explaining urban network structures are examined: distance, GDP, population, administrative borders, landform contiguity, cultural affinities, economic alliances and administrative rank. The selection of these factors is based on a combination of three meta-criteria. First, three gravity-type factors that have been widely acknowledged in simulating urban networks, i.e. distance, GDP and population, are included (e.g. Black, 1972; Krings et al., 2009; Liu et al., 2014). Second, given the fragmented regional organisation of the YRD (Zhang et al., 2017), we introduce four homophily factors that could have a potential effect on the YRD's regional formations, including administrative borders, landform contiguities, cultural affinities and economic alliances. Third, we also introduce cities' administrative rank in light of the hierarchical organisation of the party-state governance system in China, in that cities' administrative rank closely relates to

their economic status and governing power (Cartier, 2016). Below we provide a description of these variables.

- Distance

Neighbouring geographical units have closer connections, and this is deemed to be the foundation of understanding spatial interactions (Tobler, 1970). Although distance is clearly expected to have a negative effect on intercity connections, it is unclear to what degree the intercity connections in the three networks depend on distance. The Euclidean distance between the cities is used to create the variable matrix in our research.

- GDP

A city's economic performance enables it to build more connections with other cities, and also greatly affects its demand for connecting external cities. Here we adopt the GDP measure to represent the cities' economic strength. The effect of GDP is assumed to be positive in the three networks. The product of two cities' GDP is used to create the variable matrix. The data on GDP was obtained from the China City Statistical Yearbook of 2015.

- Population

Population has been widely used as a measure of a city's importance. Clearly, if a city has a larger population, this implies that it has larger business markets and larger demands for transport infrastructure. For each of the three networks, population is assumed to have more direct relations with the leisure mobility network. The product of the population of two cities is used to create the variable matrix. The data on population size was obtained from the China City Statistical Yearbook of 2015.

- Administrative borders

In China, the development of the transport infrastructure is co-organized by the central and local (provincial) governments. In this case, provincial governments have strong incentives to improve intra-provincial transport infrastructure networks. The administrative borders also have a potential influence on business networks. In the context of China's decentralisation policies of empowering local states' economic functions, 'entrepreneurial local states' (Wu, 2002) tend to protect local

firms and industries (e.g. community banks and credit unions). As a result, those locally owned businesses tend to form local networks (Oi, 1995). Additionally, the household registration system (*hukou*) in China also restricts migrant labourers (the so-called ‘floating population’) from moving freely across administrative borders (Li, 2010). We introduce a binary dummy to define the effect of (provincial) administrative borders: we assign the value 0 if a city-dyad belongs to two different provinces and 1 if a city-dyad belongs to the same province.

- Landform contiguity

Landform patterns may represent an important factor underlying intercity flows. Its effects can be hypothesized as being most obvious in the transport infrastructure network, as the type of landform relates to the accessibility of transport within a certain region. Plains and basins always have more intra-regional infrastructure connections, while cities within mountainous areas tend to have more connections with extra-regional cities. We introduce a binary dummy to define whether two cities belong to the same landform area. Values 0 and 1 are taken, respectively, to indicate the absence or presence of landform contiguity in the city-dyads. The information on landform patterns within the YRD is compiled from the self-description of Zhejiang province on its governmental website and the ‘major function-oriented zone planning’ of Anhui and Jiangsu provinces. There are 15 main landform areas within the YRD (see Appendix A in the end of the thesis).

- Cultural affinities

Cultural factors may play a potential role in knitting cities together in a network. Obvious evidence is that cultural affinities and social interactions have mostly tended to coincide (van Houtum and Lagendijk, 2001). As a result, the effect of cultural affinities on leisure mobility networks is assumed to be the most evident. Recent studies have also seen the influence of cultural affinities on local business networks (Redding, 2000). A notable example is that the development of private enterprises in Wenzhou, which is centred on family-owned small businesses, has been dependent on strong local institutions and cultures (Parris, 1993). Language affinities are adopted in this paper as a major component of cultural affinities. The dummy variables (0 and 1) are set to indicate whether the two cities in a given dyad speak the same dialects. The original data was taken from the 2010 Atlas of Chinese

Dialects (Xiong and Zhang, 2012), in which the distribution of 12 dialect zones within the YRD is delineated (see Appendix A in the end of the thesis).

- Economic alliances

The recent emergence of booming regional planning practices manifests a resurgence of domestic regionalism (also city regionalism, Wu, 2017) in the context of marketisation and decentralisation in China. Through sponsoring or joining these planned regions, local governments seek to play a role in various regional alliances (mainly in economic terms). In addition to fostering agglomeration externalities, these regional plans/alliances are also related to a range of financial rights allocated by the central government and massive infrastructure investments with the purpose of facilitating intercity interactions. Regional (economic) alliances could thus play a potential role in underlying intercity connections. In our research, we choose central state-led regional plans as a sample to define these emerging economic alliances within the YRD (see Appendix A in the end of the thesis). The dummy variables (0 and 1) are set to indicate whether the two cities in a given dyad belong to any one of the regional (economic) alliances.

- Administrative rank

In the context of the reorganisation of administrative space in China, cities with different administrative ranks (for more details about Chinese cities' administrative rank, see Ma, 2005) have different administrative and economic powers. Cities' administrative rank can thus be hypothesized to be a potential factor determining their positions in urban systems. Furthermore, administrative relations between two cities, such as provincial capitals and prefectural cities, and prefectural cities and county-level cities, strongly shape the patterns of intercity connections, and this has been clearly visible in previous studies (Zhang et al., 2016). In this paper we introduce two dummy variables to define the effects of cities' administrative rank: administrative rank-I (0 and 1) indicating whether a city dyad is consisted of two provincial capitals, and administrative rank-II (0 and 1) indicating whether a city dyad is consisted of a provincial capital and its prefectural cities.

5.3.2 Correlation and regression models

We use the quadratic assignment procedure (QAP) to perform the correlation and regression analysis. The reason for employing this approach is based on two considerations: (i) it allows us to directly calculate the correlation between two dyadic variables through controlling the non-independence of observations (Krackhardt 1988), and (ii) it can also be used to deal with categorical data without violating distribution assumptions. As the rationale of the correlation and regression analysis, based on the QAP, is similar to more traditional statistical approaches, such as multi-factor linear regression analysis, the interpretation of the results of the QAP tests, such as standardized coefficients and R^2 , is in line with such approaches.

First, we calculate the correlations between these explanatory factors and the city-dyad's connectivities within the three networks. Second, we bring different variables together in a regression model to test which explanatory factors determine the formation of each of the three networks, as follows:

$$\begin{aligned} \ln(\text{City-dyad}_{\text{-connectivity}}) = & \beta_0 + \beta_1 \ln(\text{Distance}) + \beta_2 \ln(\text{Product of GDP}) + \beta_3 \\ & \ln(\text{Product of Population}) + \beta_4 \ln(\text{administrative borders}) + \beta_5 \ln(\text{landform} \\ & \text{contiguity}) + \beta_6 \ln(\text{cultural affinities}) + \beta_7 \ln(\text{economic alliances}) + \beta_8 \\ & \ln(\text{administrative rank-I}) + \beta_9 \ln(\text{administrative rank-II}) + \varepsilon \end{aligned}$$

where β_0 is the intercept, β_i are the estimated coefficients for the independent variables, and ε is the model disturbance. Two considerations of adopting the regression model are that (i) variables are taken using the natural log transformation to reduce their skewed distribution, and (ii) the log-type transformation helps to interpret the elasticities of factors. In practice, we add a constant value (1) to each of the values of the variables before taking the log transformation, in order to deal with cases where the data has zero values (Box and Cox, 1964).

The regression analysis is conducted in a series of stepwise steps. We first bring together all of the factors in an initial model to test the statistical significance (t-test) of the regression coefficients for each of the variables. Because some variables will not pass the statistical tests in the regression model, in order to enhance the robustness of our regression results we delete the most non-significant variable stepwise and rerun the model for each network, until all of the introduced variables are statistically significant ($p < 0.05$). The remaining variables are deemed to affect

each of the three networks. All of the variables are represented in the form of a 41×41 cities square matrix. The values in each variable are normalized by the min-max method. All statistical calculations were performed in the UCINET program (Borgatti et al., 2002).

There is, of course, a concern about the possible multicollinearity in these variables. To eliminate this, we use Dekker’s ‘semi-partialling plus procedure’, a QAP test that has been verified to be robust against multicollinearity (Dekker et al., 2003) to estimate the regressions’ parameters.

5.4 Results and discussion

Figure 5.3 shows the results of the QAP correlation analysis, which confirm that almost all of the variables have significant correlations with the intercity connectivities in the three networks. The effect of cultural affinities on the business network is an exception ($p>0.05$). This has probably to do with the ‘multi-locational’ nature of PS businesses. PS firms tend to organise their work by setting up multiple branches in a large number of cities within a broader territory, for the sake of assessing ever-larger service markets and protecting their brand integrity. As a result, the intercity connections generated from intra-firm linkages are no longer driven by the constraints of cultural affinities.

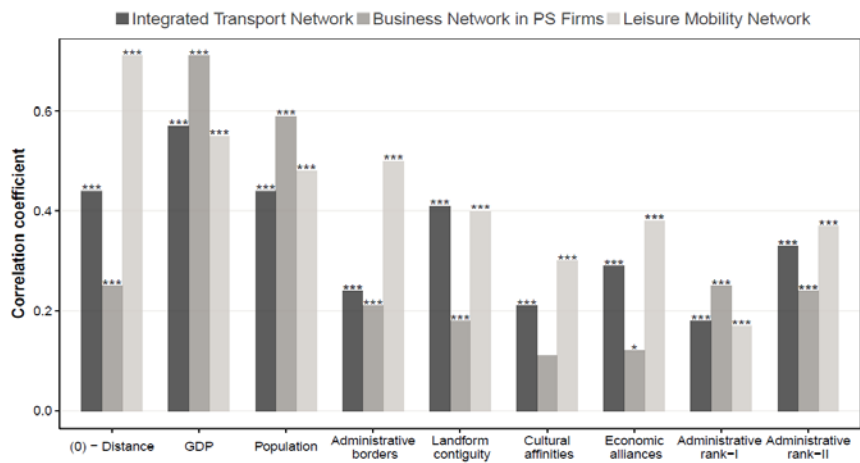


Figure 5.3. Results of the QAP correlation analysis for the three networks (* significant at 5%; ** significant at 1%; *** significant at 5%)

We bring together all of the explanatory factors in the QAP regression model to examine how they together affect the intercity connectivities of the three networks. After the stepwise deletion of the non-significant variables, Figure 5.4 charts the results of this regression analysis, in which model fits (R^2) for each model are significant at the 0.005 level. A first observation is that only some of these explanatory factors affect these networks. GDP, landform contiguity, distance, administrative rank and administrative borders affect the formation of transport infrastructure networks; GDP, administrative borders and administrative rank affect the formation of business networks; and distance, GDP, administrative borders, population and administrative rank affect the formation of leisure mobility networks, shown in the order of the explanatory factors' importance. We now discuss the different effects of these determinants and their correlations on each of the networks.

- Gravity-type factors

We first discuss three gravity-type factors, i.e. GDP, population and distance. An initial finding is that these three variables have, on average, the largest correlations for these networks. This corroborates the validity of simulating urban networks based on gravity models.

We find that GDP has the largest correlation for the transport infrastructure network and the business network, and distance has the largest correlation for the leisure mobility network (also GDP is the second most correlated factor in this network). Similarly, GDP has the statistically strongest effect on the transport infrastructure network and the business network, and the second strongest effect on the leisure mobility network in the regression analysis. As mentioned before, cities' economic size impacts the demand and supply abilities for connecting external cities. On the one hand, cities with a strong economic performance are more attractive to business activities and human mobility. On the other hand, cities' economic abilities decide their fixed (transport) infrastructure investments, and this in turn further facilitates intercity business connections and human flows. The fundamental role of cities' economic size in shaping network formation has also been evidenced in the existing literature on mapping urban networks in mainland China: despite adopting varied lenses such as producer services, air passenger transport, high speed railways passenger flows and human intercity trips (Jin et al., 2004; Wang et al., 2011; Liu et

al., 2014; Zhao et al., 2015; Yang et al., 2017), economic centres are more likely to be the most connected cities in these urban networks. However, we should be cautious in generalizing this for other regions. For instance, based on a comparative analysis of interaction-based and nodal attribute-based rankings of 39 metropolitan areas in Western Europe, Limtanakool et al. (2007) proposed that there is weak relationship between metropolitan areas' economic attributes and their connectivities in urban networks, and thus economic attributes alone would not be a good proxy for ranking cities' positions from an interaction perspective.

In contrast with GDP, population is not a determinant in the transport infrastructure network and the business network, while its effects are visible in the leisure mobility network. Clearly, the size of population is directly related to the volume of intercity mobility, while the economic performance of cities is more strongly related to intercity infrastructure linkages and flows of business. However, an additional reason may be traced back to the spatial mismatch between population and economic distribution within the YRD. The most evident example would be the sizable regional inequality between northern and southern Jiangsu (Wei and Fan, 2000). For example, despite representing 38% of the population, the northern Jiangsu only generated 23% of the provincial GDP in 2015. This also offers a useful reference to the indicator selection of city size (i.e. GDP vs population) when modelling different types of urban networks.

The negative correlation between the factor of distance and the business network is relatively weak in comparison with other factors or other networks. Correspondingly, the negative effect on the business network does not remain in the regression analysis. This relates to the organisational forms of PS business flows: the technological revolution – especially the development of computer and communication industries – enables multilocal PS corporations to run their internal businesses across long distances. The intercity business flows that we have mapped in this paper focus on such intra-firm linkages. Additionally, results also suggest that leisure mobility is most affected by distance decay (e.g. Brockmann et al., 2006).

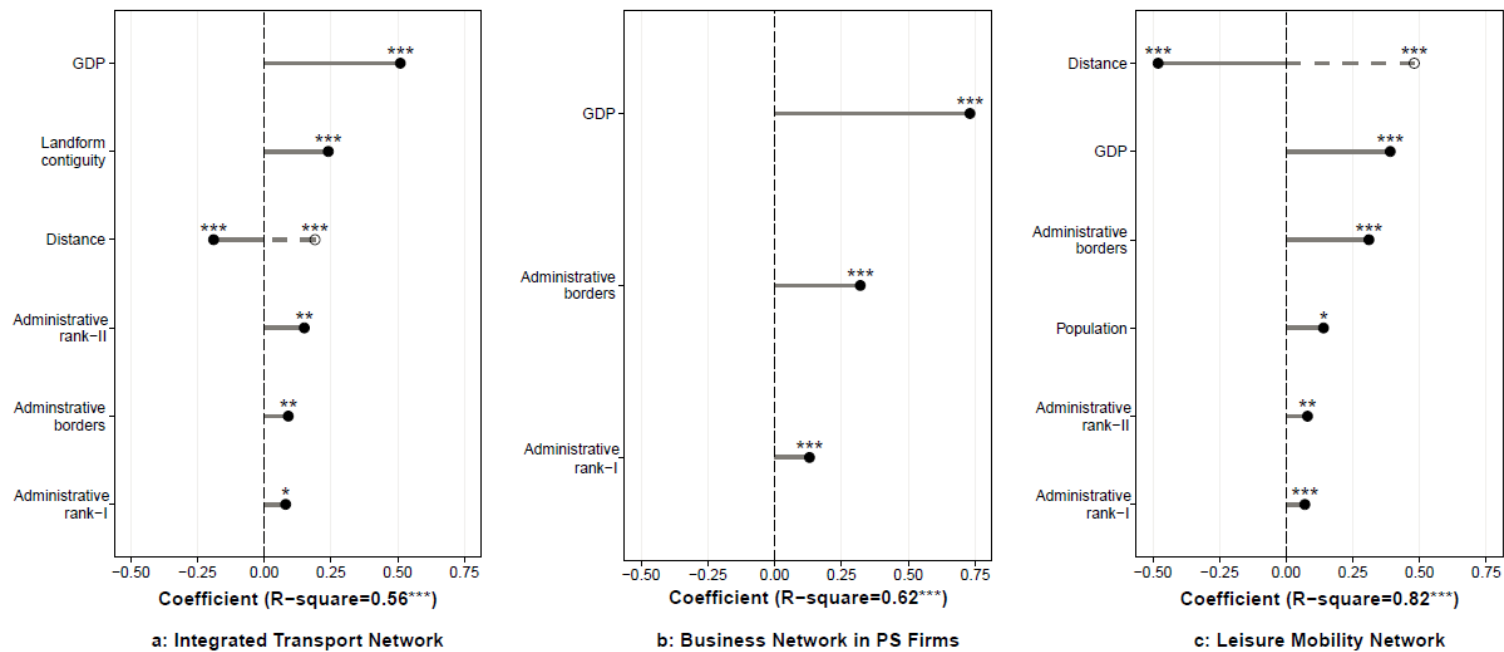


Figure 5.4. Results of the QAP regression analysis for the three networks (* significant at 5%; ** significant at 1%; *** significant at 5%)

- Homophily factors

The provincial borders within the YRD were found to strongly affect all the three types of flow. Although the presence of regional boundaries in a ‘space of flows’ has been deemed fuzzy and porous (Amin, 2004; Paasi, 2004), the boundary effects in China are assumed to be quite strong (cf. Ma, 2005). This is because the spatial organisation of the regions and cities in China tend to follow the territorial configuration of political space (Ma, 2005). In this context, provincial level units were authorized to regulate their subordinate cities by way of fiscal allocation and cadre management. The political intervention embedded in the regional organisation has hence reinforced administrative borders (Chien and Gordon, 2008; Li and Wu, 2017). Furthermore, the effect of administrative borders on the mobility network stands out. One reason for this may be that the Chinese household registration system (*hukou*) and a series of related regulations limit free human flow, in spite of the fact that the *hukou* barriers have been gradually undermined. For example, non-local *hukou* holders are not qualified to buy local properties or enjoy basic healthcare insurance.

With regard to the other three homophily indicators in the regression analysis, with the exception of the effect of landform contiguity on transport infrastructure network, they do not decisively affect the formation of these networks, in spite of the presence of significant correlations. The key point here is that the relationship between economic alliances and intercity connections is not as significant as that between other factors and intercity connections, although economic alliances are orchestrated to facilitate regional coordination. This reminds us that there is a need to thoroughly examine whether these multi-level government-orchestrated regional alliances are as closely connected as they claim.

- Administrative rank

As a product of restructuring China’s political geographies, the role of the administrative rank of cities in shaping these networks is visible. This is in line with the observation of Zhang et al. (2016) on the YRD’s hub-and-spoke mobility network between prefectural cities and provincial capitals. Provincial capitals are usually the largest cities of provinces in terms of population and GDP (Yeh and Xu, 1984), and, more importantly, they are given a privileged position in the distribution

of fiscal and administrative power. These factors make it easier to attract the setting up of branches of PS firms, encourage human migration and facilitate the improvement of connectivities for the transport infrastructure. Furthermore, relations between provincial capitals have particular effects on the business network. This corresponds with the backbone of the business network, as previously noted: four provincial capitals are the spatial foci in which the main PS business flows take place. By investigating the location strategies of the 247 PS firms within the YRD, we find that most of them have set up regional and/or provincial headquarters in these provincial capitals. Thus hub cities in the political system always becomes the hub of business flows, a regional (provincial) gateway into and out of broader national market for services.

5.5 Conclusions

In this research we have examined the different determinants underlying three types of urban networks connecting the YRD. Two meta-findings stand out. First, all of the explanatory factors included in our analyses have significant correlations with the three urban networks – with the exception of cultural affinities for the business network – but their correlations differ significantly based on the type of intercity connections. However, and second, only some of these explanatory factors decisively affect each of the three networks: GDP, landform contiguity, distance, cities' administrative rank and administrative borders affect the formation of transport infrastructure networks; GDP, administrative boundaries and cities' administrative rank affect the formation of business networks; and distance, GDP, administrative borders, population and cities' administrative rank affect the formation of leisure mobility networks, shown in the order of the factors' importance.

These empirical findings reflect the different determinants shaping the multiplexity of urban networks on the one hand, but also enhance our understanding of the YRD's regional formation on the other hand. As regards the determinants of the multiplexity of urban networks, the main observations are that the 'multilocal' nature of PS firms enables the business network to alleviate its dependence on distance and cultural affinities; intercity mobility is closely related to the size of

cities' populations and intercity distance; and landform patterns remain a fundamental basis for intercity transport linkages. As regards the YRD's regional formation, our research shows that the cities' economic attributes, administrative boundaries and administrative rank play a key role in constructing intercity interactions within the YRD. This reflects the particular context of China's regional organisation such as party-state territorialisation.

Notes

1. Apart from railway and bus linkages, a comprehensive transport infrastructure network should include air and road connections. For the former, the YRD has sparse inner air flows due to the relatively small geographical scale. For the latter, we tested the maximum speed of intercity movements through Google Maps, which can be deemed an efficiency indicator of road connections. Because of the well-developed expressway network within the YRD, the result points to an even pattern of the intercity road connections.

2. The information was mainly collected from annual reports published by sectoral associations. The initial list of firms includes 50 top accounting firms (source: goo.gl/TDDy9p), 50 top advertising firms (source: goo.gl/37FERZ), 50 top management consultancy firms (source: goo.gl/v43XI5), 35 law firms (source: goo.gl/OsCspB), 21 main nationwide banks (source: goo.gl/fwHRMr), 30 top insurance firms (source: goo.gl/2z7oW9), 30 top security firms (source: goo.gl/gcFhg8) and 30 top trust firms (source: goo.gl/Pvn2Zh) in mainland China. Given that some of these firms did not offer information on where their major service offices are located on their websites, the final list includes 247 firms.

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6. Regionalisation in the Yangtze River Delta, China, from the perspective of intercity daily mobility

Zhang W, Derudder B, Wang J and Shen W. (2017) Regionalisation in the Yangtze River Delta, China, from the perspective of intercity daily mobility. *Regional Studies*. Doi: 10.1080/00343404.2017.1334878 (online first)

Abstract

This paper attempts to understand the Yangtze River Delta (YRD)'s regional organisation by describing an interaction-based regionalisation based on patterns of actual daily mobility and discussing how such patterns relate to possible attribute-based regionalisation. By applying a community detection algorithm, we divide the YRD into sub-regions in which cities are more closely connected to one another, and compare the interaction-based regionalisation with physical–economic–cultural–administrative (PECA) regionalisation. The results show that political boundaries and historical patterns of socio-economic integration are strikingly visible, and the effects of overlapping physical, economic, cultural and administrative spaces on regional integration are apparent. We conclude that regional formations are bound through interconnected socio-economic activities, while the ‘bounded’ network organisations can be viewed as the product of the underlying territorially embedded spaces. In addition, ‘historical paths of regional formation’ also play an important role in understanding regional relational configurations.

6.1 Introduction

In the literature on mega-city-regions (Hall and Pain, 2006) or their near analogues such as global city-regions (Scott, 2001) and polycentric metropolises (Kloosterman and Musterd, 2001), the development of China's mega-city-regions has attracted increasing attention (Xu and Yeh, 2010; Vogel et al., 2010; Li and Phelps, 2016; Liu et al., 2016; Liu et al., 2017; Zhang and Kloosterman, 2016). One basic characteristic of China's megacity-regions is their considerable geographical extent. For example, the Yangtze River Delta (YRD) – an archetypal mega-city-region in China – is substantially larger than its ostensible counterparts in other parts of the world, such as the South East of England and the Dutch Randstad. According to the geographic delineation adopted in the YRD Urban Agglomeration Development Plan (YUADP), as implemented by the National Development and Reform Commission, the region covers an area of 211,700 km², which is comparable in size with the UK as a whole. Within such a large territorial framework, the regional diversification of physical, economic, cultural and administrative spaces becomes obvious. The YRD spans plains, basins and mountains; includes multiple economic alliances designated by multilevel governments; stretches across different cultural areas; and consists of four provincial-level political spaces. To date, relatively little attention has been paid to this regionalisation within China's megacity-regions. In this paper, we seek to address this research lacuna by examining regionalisation within the YRD.

Regionalisation research has long relied on attribute-based approaches, whereby homogeneous regions have been delineated based on geophysical, economic, socio-cultural or political commonalities. However, it has been recognized that such attribute-based regionalisation and their absolute boundaries can be supplemented or replaced by interaction-based regionalisation in which territories are deemed 'unbound' (cf. Amin, 2004). The key point supporting this argument is that regional delineations generated through an attribute-based approach may fail to reveal how the territorial coherence of regions is (re)created: a 'region' is above all (re)produced through processes of spatially interconnected socio-economic activity. More specifically, this approach recognizes that regions should not reflect preconceived frameworks that may or may not reflect activity and flows within and across a given

regional space. Rather, such frameworks are at best a heuristic device that captures a significant part of the geography of interconnected socio-economic activity (Pred, 1984; Söderbaum and Taylor, 2008). Following this rationale, this paper attempts to understand the YRD's regional organisation by describing an interaction-based regionalisation based on patterns of actual daily mobility and discussing how such patterns relate to possible attribute-based regionalisation.

This objective is achieved in two consecutive steps. First, we 'regionalize' by analysing network formation in the YRD from the perspective of the density of intercity interaction. The 'network turn' (cf. Ducruet and Beauguitte, 2014) in urban research has stimulated research that is useful for creating such 'interaction-based' regions. For instance, Taylor et al. (2013) recently presented a specific regional geography of globalisation based on the uncovering of regionalized location strategies of leading advanced producer service firms. In our research, we apply a community¹ detection approach to divide the YRD into sub-regions in which cities are more closely connected to one another. The information on intercity mobility is derived from Weibo, a major Chinese online social networking and micro-blogging service. Because Weibo users can 'geo-tag' their movements, Weibo has the potential to link social practices to intercity engagements (Zhang et al., 2016). Second, this interaction-based regionalisation is compared with physical-economic-cultural-administrative (PECA) regionalisation. In this way, the link between this interaction-based regionalisation and territorial regional formation can be investigated.

This paper also has a second objective. Through primarily empirical research, we seek to contribute to the conceptual debate on the coexistence of 'networks' and 'territories' in the (re)productions of regions. The debate on whether a region is 'territorially embedded' or 'relational and unbound' has been addressed from a range of social and economic-geographical perspectives (e.g., Thrift, 1983; Giddens, 1984; Gilbert, 1988). Although it has been recognized that 'territorialisation' and 'networking' combine as a 'regional world' that is (re)configured (Hudson, 2007; Jessop, Brenner, and Jones, 2008; Harrison, 2013), there is relatively little empirical research that attempts to confront the approaches. Therefore, this paper can also be viewed as an empirical investigation of how the approaches interact.

The paper is structured as follows. The next section provides a general discussion of the PECA regionalisation of the YRD. It is followed by a section in which we introduce our data and methods. The subsequent results section is presented in three parts: a discussion of the interaction based regionalisation, the comparison of such regionalisation with PECA regionalisation, and a discussion on the similarities and differences between the two. The paper concludes with an overview of its major findings, policy implications and suggestion for avenues of future research.

6.2 Division of the YRD's regional spaces

In this section, we present the *territorial* PECA regionalisation of the YRD. Territories have long been understood as bounded and fixed spaces that have some type of intra-territorial coherence. This coherence can have geophysical, economic, socio-cultural and political characteristics. In contrast, 'network' indicates interconnected socio-economic practices, which reflects an understanding of regions as unbound, fluid and relational. Although territory and network seem to be rival ideas of spatial organisation, there is increasing support for the argument that they should not be viewed as incommensurable but as interconnected and concurrent (Macleod and Jones, 2007; Jones, 2009; Painter, 2010; Harrison, 2013). As Painter (2010, p. 1090) notes, 'territory can be seen as itself a product of relational networks'. For instance, a 'cultural region' can be understood as the outcome of historical interconnections of culture-related social practices, such as language. From this standpoint, we introduce the territorial division of the YRD in line with the 'economic, cultural, environmental and political projects' proposed by Jonas and Ward (2007, p. 176): (1) hierarchical administrative divisions, (2) uneven landform patterns, (3) language-based cultural disparities and (4) emerging regional (economic) alliances (created by multiple central state-led regional plans).

In our study, the YRD is understood to include Jiangsu, Zhejiang and Anhui provinces and the municipality of Shanghai. It consists of 89 statutory cities: one municipality-level city, 40 prefecture-level cities and 48 county-level cities (Figure 6.1(a); for city codes used in the Figures, see Appendix B in the end of the thesis).² The region is arguably one of China's main economic engines. Although it only occupies 3.6% of the nation's total land resources and is home to 16.6% of the

population, the region generated 23.5% of the national gross domestic product (GDP), 23.9% of the national fiscal revenue, and received 41% of China's inward foreign investment in 2014.

- Administrative regions

Administrative barriers may play a crucial role in regional (re-)production through regulating fixed spatial configurations and territorial assets, such as infrastructure (Zhang and Wu, 2006). Since the economic reforms started in 1978, China has adopted a series of decentralisation policies that empower local states in the distribution of administrative and economic powers with the central government. The emerging 'entrepreneurial local states' (Wu, 2002) epitomise this transformation of the governance system. That is, local governments have strong incentives to shield local firms and industries from interregional competition. At the same time, another factor contributes importantly to the territorial division of the YRD: the unique household registration system (*hukou*), which institutionally restricts migrant labourers from moving freely across different administrative borders. Taken together, the effects of the administrative borders on socio-economic interaction have persisted and are probably much stronger than in the West, where 'the effects of territorial boundaries on the flows of local and non-local forces are not absolute as the boundaries are generally porous' (Ma, 2005, p. 484). Figure 6.1(a) maps the administrative divisions at the provincial and prefecture scale.

- Uneven landform regions

Regional identity has often been affected by physical boundaries. Prior to the Industrial Revolution, physical conditions profoundly restrained people's movements and related socio-economic activities. Thus, the geographical environment often shaped intercity interaction. Industrialisation has resulted in a substantial shift in mobility and accessibility through the rapid construction of large-scale transportation infrastructures. Additionally, the development of information technology has reduced the constraint of physical space and distance. However, physical boundaries may still act as a significant complement to social and economic interactions, particularly those that involve physical flows at a regional scale. For instance, the Northeast Zhejiang Plain Region within the YRD has been well

connected with other cities within northern China through a network of rivers and canals since the Sui dynasty (581– 618 CE), and this network has been considered one important reason for its contemporary prosperity (Lin, 1992). Landform patterns are adopted in this paper as a major component of the physical environment. Figure 6.1(b) presents a regionalisation based on 15 landform regions.³ The regionalisation is based on the landform partitions in the ‘major function-oriented zone planning’ (a main spatial planning system in China) of Anhui and Jiangsu provinces and the self-description of Zhejiang province at its governmental website.

- Language-based regions

Linguistic affinities may also consolidate socio-spatial segregations and agglomerations (Wu et al., 2016) and thus could play an important role in the (re)production of regions. In the Chinese context, although Mandarin Chinese (*Putonghua*) is the official language, significantly different dialects and local languages exist, among which Cantonese is a well-known representative. These dialects were historically associated with administrative regions during imperial times. However, they have also been essential for China’s contemporary socio-economic interaction. A typical example is how the distinct Oujian dialect in Wenzhou facilitates the formation of the ‘thick’ local institutions of that region’s business networks (Wei et al., 2007). Figure 6.1(c) maps the YRD’s dialect zones to show the language-based cultural disparities, whereby four dialect zones and 12 sub-dialect zones are delineated. The original data are from the 2012 Atlas of Chinese Dialects, which documents the results of the comprehensive language survey organized by the Chinese Academy of Social Science (Xiong and Zhang, 2012). Generally, the dialect patterns within the YRD are diverse, and the Taihu dialect zone is broadly in line with the YRD’s core region.

- Emerging regional (economic) alliances

Another product of China’s economic/administrative restructuring is the emergence of intercity cooperation in response to interregional friction. The increasing regional (economic) alliances manifest themselves through the mushrooming of regional plans, formal/informal regional cooperation and large-scale administrative annexation (Ma, 2005; Li and Wu, 2013). An obvious example is the proliferation of

multiple central state-led regional plans (CSLRPs; for CSLRP codes, see Appendix C in the end of the thesis) through which the central government has reasserted its power in regional governance (Chen et al., 2014). Local governments aspire to be designated an ‘urban region’ to pursue their economic interests and showcase their strategic importance (Liu et al., 2016; Wu and Zhang, 2007). As a consequence, the YRD’s spatial organisation seems to have been restructured into a fragmented, overlapping combination of a series of regional alliances (Chen et al., 2013). In our research, we map the emerging urban regions designated by CSLRPs as our sample of these regional alliances within the YRD. Figure 6.1(d) maps the CSLRPs that cover more than one YRD city promulgated since 2010.⁴ The multiple overlaps of the CSLRPs are notable. For instance, Nanjing is included in three CSLRPs, i.e., PSMDA (Plan for Sunan Modernisation Demonstration Area), RPNM (Regional Plan for Nanjing Metropolitan) and RPYRD (Regional Plan for the Yangtze River Delta), which indicates its close cooperation with Southern Jiangsu, the Nanjing city-circle and the core region of the YRD (i.e., Jiangsu and Zhejiang provinces and the municipality of Shanghai), respectively.

6.3 Data and methods

6.3.1 Deriving human mobility information from Weibo

In this section we describe the Weibo data we use and test their validity in the context of our research. Weibo, which means ‘microblog’ in Chinese, can best be described as a hybrid of Twitter and Facebook. Its users are allowed to post short texts that express impressions, information and daily activity. They can also share their location through a ‘geo-tagged’ service. A geo-tagged post contains information on where and when the user posted the message. Thus, a user who multi-tags information in different cities has the potential to reflect his/her intercity mobility. In a previous study (Zhang et al., 2016), the potential of Weibo data for analysing intercity geographical patterns was verified. Here, we focus on the data required for this particular study and an approach for generating day-to-day intercity movements from geo-tagged records.

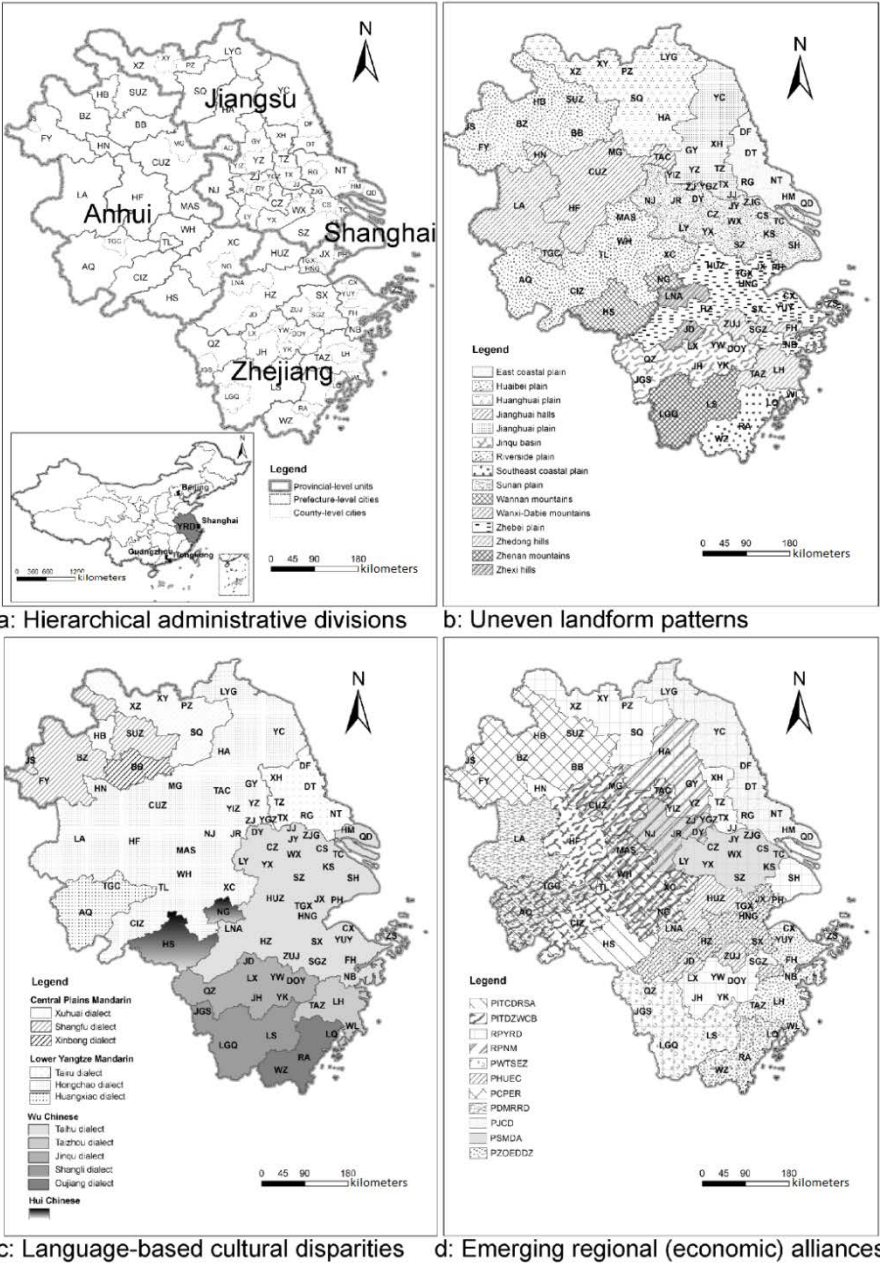


Figure 6.1. Attribute-based regionalisations of the Yangtze River Delta

Weibo provides a public application-programming interface (API) for application developers to search and download messages. In our study, the API was used to gather the geo-tagged records submitted within the YRD between January 2014 and

November 2014. The dataset contains 53.52 million geo-tagged records, which is 6.05% of all Weibo records submitted in the same region and period. These geo-tagged records were posted by 7.03 million users, which is 32.89% of the monthly active users registered in this region⁵ and 3.09% of the overall regional population. These records provide information on post content as well as spatial (geographic coordinates) and temporal information associated with the post. Following Llorente et al.'s procedure (2015) for generating Twitter users' intercity travel, this paper assumes that a trip has occurred if the user has successively posted geo-tagged records in two cities within two successive days. The reason to apply two successive days as a time restriction is based on a couple of considerations: (1) the two-day duration ensures that Weibo users can travel between the city pair with the greatest distance – the maximum trip time is more than 10 hours – and have sufficient time to post geo-tagged records; while (2) adopting a longer time interval would reduce the reliability of deriving intercity direct movements from successively posted records. Based on a hypothetical example in which a user posts seven geo-tagged messages in six cities within May, Figure 6.2 shows how the intercity mobility network is constructed. The resulting dataset includes more than 0.78 million records of intercity trips among the 89 statutory cities, which is 38.32% of all generated mobility records that consist of inter- and inner-city trips.

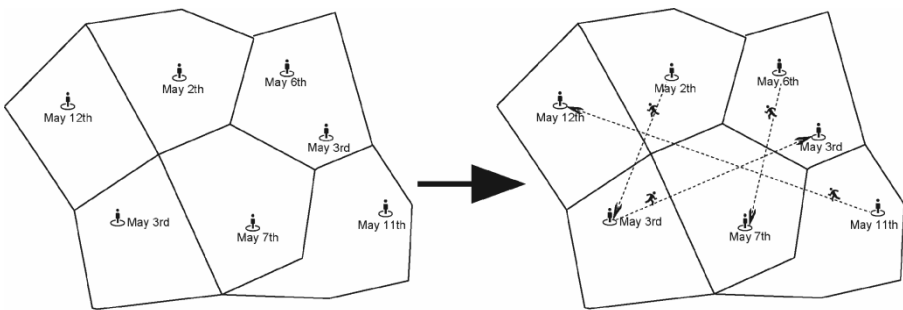


Figure 6.2. Definition of intercity trips based on Weibo users' geo-tagged records

Our geo-tagged Weibo posts only represent a sample of all Weibo records, and Weibo users only represent a sample of the overall population. To test the representativeness of Weibo records, we first check the demographic composition of Weibo users in terms of gender and age. Given the concern of personal privacy, our

data do not contain users’ socio-economic characteristics. We refer to the Weibo users annual statistic report issued by Sina Corp, which shows that Weibo users are predominantly found among younger groups (the group aged between 17 and 33 occupies 83% of total users) and the gender proportion is balanced. However, our study assesses the overall formation of human movements at an aggregate level, and we see no reason why this bias towards youth groups will result in a meaningful regional bias. Recent studies have suggested that social media sampling is suitable for representing aggregated human activity, particularly in cases in which individual human mobility data are sparse in China and many other countries (Mayer-Schönberger and Cukier, 2013; Wu et al., 2016). However, in order to emphasise further the validity of the Weibo data, we investigate the spatial representativeness of Weibo sampling using population distribution data from the Statistical Yearbooks of Shanghai, Jiangsu, Zhejiang and Anhui provinces (2014) as a benchmark. Figure 6.3 shows high correlations between each city’s population and its geo-tagged Weibo users as well as geo-tagged Weibo records, with correlation coefficients of 0.94 and 0.95 ($*p < 0.001$), respectively.

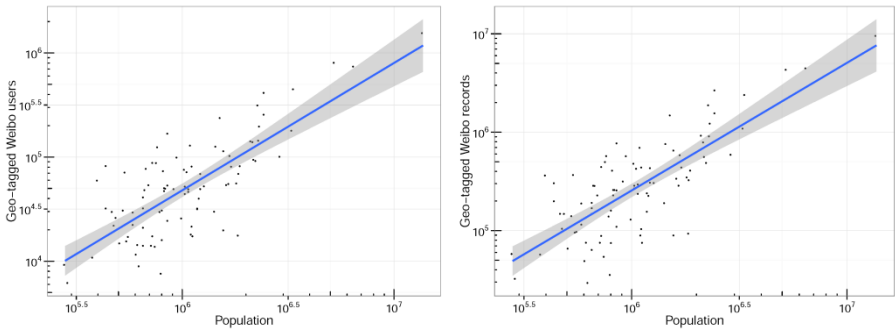


Figure 6.3. Correlations between cities’ population, their number of geo-tagged Weibo users and the number of geo-tagged Weibo records

(We normalized these variables using a log transformation to alleviate the skewness in their distributions. The grey area surrounding the solid line shows the 95% confidence interval.)

6.3.2 Regionalisation based on intercity human movements

The purpose of this section is to divide the YRD into smaller sub-regions in which cities are more strongly connected to one another. The community detection approach in network science, which is used to partition a network into clusters with stronger connections, is a useful tool to achieve this regionalisation. This paper employs the community detection approach known as the fast greedy method (Clauset et al., 2004). The method is a hierarchical agglomeration technique that operates by optimizing Newman–Girvan modularity (Girvan and Newman, 2002).⁶ Because many networks are characterized by hierarchically nested structures, this method facilitates identifying these nested communities using stepwise detections. In this research, the community detection procedure was performed on the R statistical platform using the igraph package (Csardi and Nepusz, 2006). Four communities were detected at the first detection (see the results section). However, the four generated communities seem to fail to reveal the fragmented space of the YRD at a smaller scale (for instance, the YRD consists of 12 dialect zones, 15 landform pattern zones and 11 CSLRP zones). To address this issue, we further detected the (sub-)communities within the first-step communities. Thus, the resulting regionalisation is a two-tier partition.

6.3.3 Comparing interaction- and attribute-based regionalisation

Comparing different regionalisations can be achieved through an assessment of the probability that a pair of cities in the same group in a regionalisation setup also belong to the same group in the other regionalisation. To this end, we propose the following criterion for assessing this probability:

$$F(P, P') = \frac{NI}{NP} \quad (1)$$

where $F(P, P')$ represents the correlation index between the attribute-based regionalisation (P) and the interaction-based regionalisation (P'); NI represents the number of city pairs in the same group under both P and P' ; and NP represents the number of city pairs within the communities under P . This criterion awards a value of 0 for two completely unrelated partitions. However, the maximum possible value of $F(P, P')$ is dependent on the possible maximum of NI . If the possible maximum of NI is smaller than NP , the possible maximum of $F(P, P')$ is less than 1. To facilitate our comparisons, we therefore report normalized values of $F(P, P')$ in such

a way that the values are in the range [0, 1], where 0 indicates absolutely unrelated and 1 indicates perfect correlation. The normalisation is given by the following:

$$F'(P, P') = \frac{F(P, P')}{F_{max}(P, P')} \quad (2)$$

$$F_{max}(P, P') = \frac{Min(NP, NP')}{NP} \quad (3)$$

where $F'(P, P')$ represents the normalized correlation index; $F_{max}(P, P')$ represents the possible maximum of $F(P, P')$; NP' represents the number of city pairs within the groups under P' ; and $Min(NP, NP')$ represents the minimum of NP and NP' . Applying formulas (1) to (3) allows for a comparison of the interaction-based regionalisation with the various PECA regionalisation to be made.

6.3.4 Benchmarking the intra-connectivity of sub-regions

Finally, to understand further the relationship between interaction-based regionalisation and the PECA regions, we benchmark the intra-regional connectivity of the putative sub-regions in the attribute-based regionalisation using a two-step approach.

First, we calculate the dominance index of the intra-connectivity (DI) of each sub-region. This index is formulated as the ratio between the average strength of the intercity connections within the sub-region and the average strength of the outward connections of the involved cities:

$$DI = \frac{Intra-connectivity}{Extra-connectivity} \quad (4)$$

Second, we benchmark the dominance index of the intra-connectivity of each sub-region against the average dominance of the intra-connectivity of the sub-regions of the interaction-based regionalisation:

$$DI' = \frac{DI}{\sum_{j=1}^J \frac{DI_j}{J}} \quad (5)$$

where DI' is the benchmarked intra-connectivity; and DI_j is the dominance index of the intra-connectivity of sub-region j in the interaction-based regionalisation. A value > 1 indicates that the degree of regional integration of the sub-region is

stronger than the average integration scenario of the interaction-based regionalisation, while a value < 1 indicates that the degree of the regional integration of the sub-region is less than the average integration scenario of the interaction-based regionalisation.

6.4 Results

6.4.1 YRD's regionalisation: Spatial adjacency and expected patterns

This section reports the general patterns of the interaction-based regionalisation. Figure 6.4 maps the two-tiered regionalisation of the YRD. The first step in the detection produces four sub-regions, which are simply termed the central, northern, western and southern sub-regions for reasons of clarity. The iterative detection for these sub-regions produces 14 second-tier sub-regions, which are labelled according to their major cities (i.e., prefecture-level cities). The average modularity of these partitions ($\bar{M}=0.31$) is indicative of the strong cluster structures in the resulting sub-regions (Newman, 2006).⁷

To check the robustness of the detection results, two other state-of-art community detection algorithms, i.e., Walktrap (Pons and Latapy, 2005) and Multi-Level (Blondel et al., 2008), are used and their results are compared. The test of similarity is achieved by performing the normalized mutual information (NMI) procedure (Ana and Jain, 2003), which is used for comparing clustering results. It is obtained by:

$$S(P_a, P_b) = 2 \frac{I(P_a, P_b)}{H(P_a) + H(P_b)} \quad (6)$$

where $S(P_a, P_b)$ represents the similarity of the two partitions (P_a and P_b) of community, ranging from 0 (absolute dissimilarity) to 1 (perfect similarity); $I(P_a, P_b)$ is the mutual information between the two partitions, $H(P_a)$ and $H(P_b)$ represent the entropies of both partitions (for more details on the calculation of $I(P_a, P_b)$, $H(P_a)$, and $H(P_b)$, see Ana and Jain, 2003). Table 6.1 represents the results of the robustness test, which shows that the communities obtained from the different methods are highly similar.

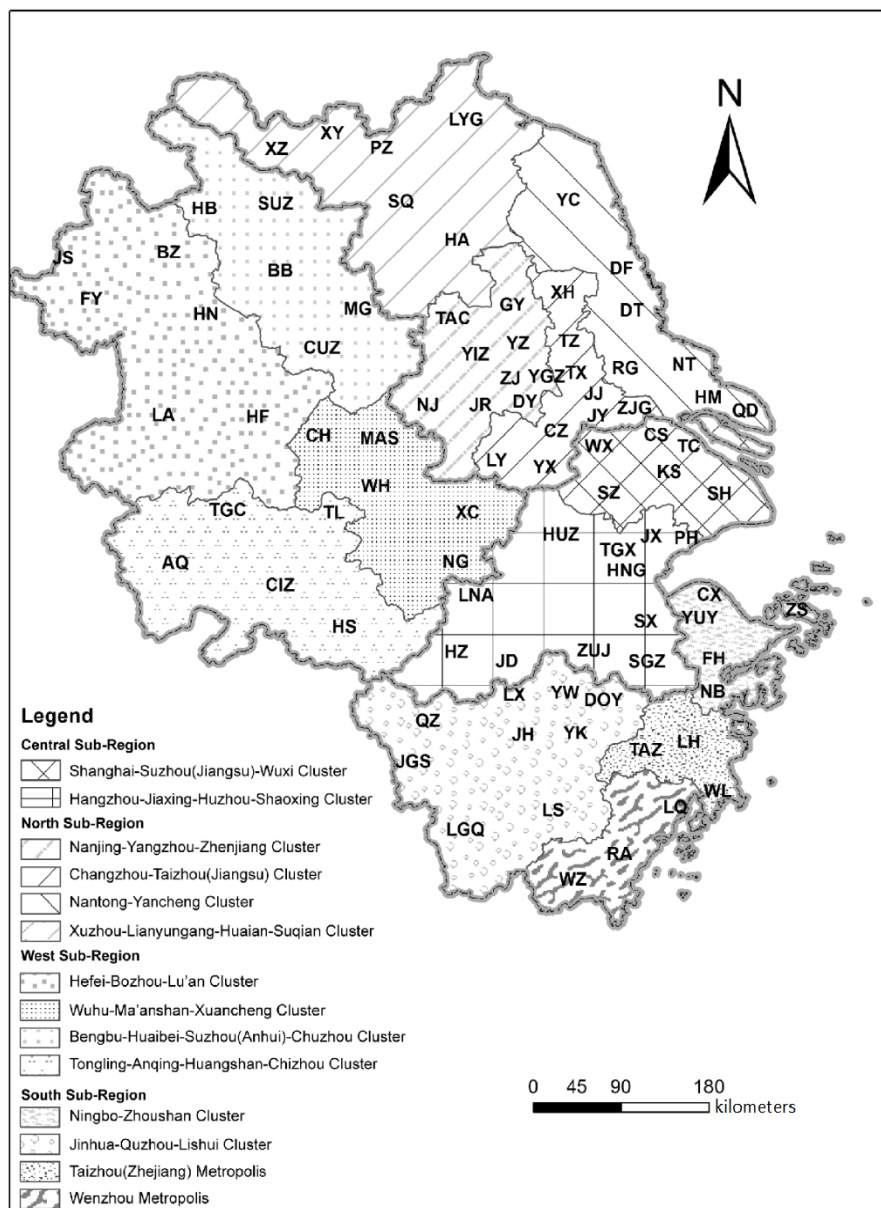


Figure 6.4. Interaction-based regionalisation of the Yangtze River Delta

Two initial observations can be made based on the regionalisation. First, the cities within the same communities are perfectly spatially adjacent. If one bears in mind that the generated partition is based on the network's topology rather than considering the spatial attributes of cities, the complete spatial adjacency within all

communities provides convincing evidence for the fundamental effect of distance and spatial adjacency on intercity connections although the nature of the geographical patterns is of course that neighbouring territorial units have closer connections (cf. Tobler, 1970).

Second, the overall pattern is unsurprising. Except for the central sub-region, the territories of the first-tier sub-regions are generally in accordance with provincial borders, while the second-tier sub-regions also correspond to pre-existing, integrated socio-economic clusters. For instance, the Nanjing–Zhenjiang–Yangzhou cluster, which was established by local governments over 10 years ago and is now an integrated city cluster (*Ning-Zhen-Yang Tongchenghua* in Chinese), is clearly indicated. The *Oujiang* dialect zone, where non-natives are barely able to understand the local language because of its tonal complexity, stands out as an individual community. In addition, the *Huanghuai* Plain, where cities share a similar *Han* cultural background and industrial structure and have suffered the same historical catastrophes, such as repeated massive Yellow River floods and avulsions (which strengthened the emotional affinity and self-identification of the region’s inhabitants; Zhou, 1993), is reproduced in this regionalisation. However, to what extent is the proposed regionalisation systematically in line with the PECA partitions? The next section presents a quantitative analysis of this question.

Table 6.1. Results of NMI measurement comparing the generated partition with the outcomes obtained by Walktrap and MultiLevel algorithms

Methods	First step detection	Second step detection			
		Central Sub-region	North Sub-region	West Sub-region	South Sub-region
MultiLevel	0.89	1.00	1.00	1.00	0.84
Walktrap	0.78	1.00	0.75	0.58	1.00

6.4.2 Comparing different regionalisations

Table 6.2 summarizes the correlation indices between the interaction-based regionalisation and the different PECA regionalisation. Generally, the four PECA regionalisations exhibit obvious correlations with the pattern of intercity connections that are reflected in the interaction-based regionalisation (with correlation indices

over 0.45, meaning that over 45% of the city pairs are in the same group under two partitions). Most notably, administrative boundaries have the strongest influence on intercity connections, with a correlation index of over 90%. In addition, these correlations vary across the sub-regional tier. For instance, CSLRPs have a closer connection to the first-tier communities (with a correlation index of 0.84), while the connection strength largely decreases with the second-tier communities (with a correlation index of 0.48). Thus, the effects of the PECA spaces on regional integration should be separately discussed at different scales. The correlation indices are the evidential basis on which the majority of analyses are based in the following section.

Table 6.2. Correlation indices between the interaction-based regionalisation and traditional regionalisation

Traditional regionalisation	Interaction-based regionalisation	
	First-tier communities	Second-tier communities
Provincial territories	0.90	0.96
Prefecture-level territories	0.91	0.90
Dialect zones	0.56	0.75
Sub-Dialect zones	0.45	0.63
Landform zones	0.70	0.52
Central State-led Regional Planning territories	0.84	0.48

6.4.3 Parallels and differences with the PECA regionalisation

This section identifies the main similarities and differences between the interaction-based regionalisation and the PECA regionalisation by assessing (1) ‘cross-(administrative) border cities’, (2) the intra-connectivity of landform regions, (3) the intra-connectivity of dialect regions and (4) the intra-connectivity of the urban regions designated by the CSLRPs.

- Cross-(administrative) border cities

The cross-(administrative) border cities are singled out using the following criteria: if a city and more than half of the cities within the same community belong to

different provinces, the city is defined as a cross-provincial border city; if a county-level city and its superordinate prefecture-level city belong to different communities, the county-level city is defined as a cross-prefecture border city. Figure 6.5 maps these cities.

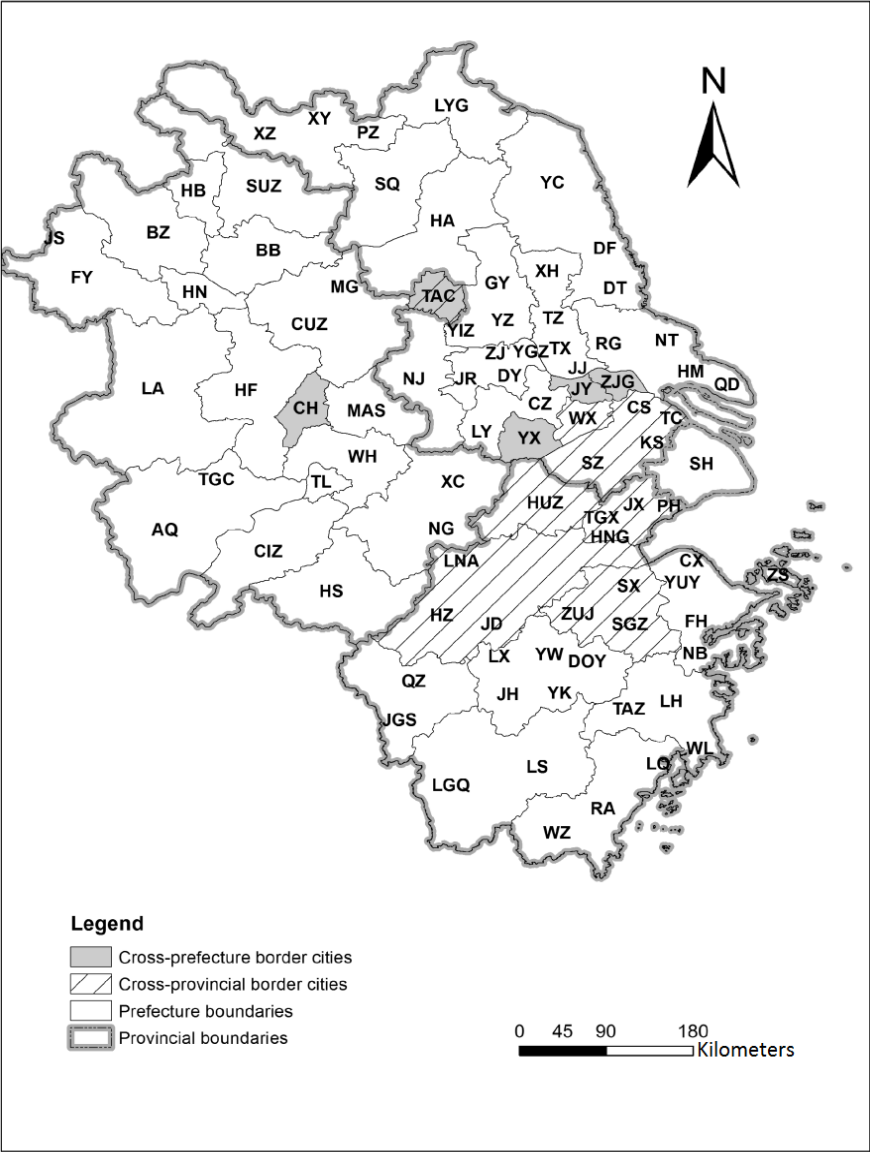


Figure 6.5. Cross(-administrative) border cities within the Yangtze River Delta

The first observation is that the central sub-region in the generated regionalisation, which consists of the key cities that surround Shanghai, results in most of the provincial border-crossing cities being located within the Jiangsu and Zhejiang provinces. It also creates the cross-prefecture borders for Jiangyin, Zhangjiagang and Yixing, which belong to the Suzhou and Wuxi prefecture cities with respect to administrative relationships but are not placed in the central sub-region. This ‘prefecture-border breaking’ can be attributed to two factors. On the one hand, without exception, these three cities are the most economically successful county-level cities in China. Their outstanding economic performance has enabled them to accumulate greater financial power and administrative competency and thus decreased their dependence on their superordinate prefecture-level governments. On the other hand, these cities are a long commuting distance from Shanghai (over two hours by car) and lack direct high-speed railway connections. Their counterparts in this region, such as Taicang and Kunshan, are located within commuting distance of Shanghai and attract many Shanghai workers who wish to reside in the area. Therefore, these cities are tightly grouped, as can be observed in the generated regionalisation. Second, Tianchang breaks both the provincial and prefecture borders. Its ‘border breaking’ can be understood from two aspects. On the one hand, geographically, Tianchang – nicknamed ‘the eastern door of the Anhui province’ – is deeply embedded in the territory of Jiangsu province. More specifically, it is closer to Yangzhou – the adjacent prefecture-level city in Jiangsu province – than to its superordinate prefecture-level city, Chuzhou. On the other hand, historically, Tianchang was part of Yangzhou from 742CE to 958CE during the Tang dynasty. During that long period, the dialect of Tianchang and Yangzhou formed. The combination of the spatial and historical factors as well as the more advanced economy of Yangzhou has resulted in closer connections between Tianchang and Yangzhou. Third, the ‘border breaking’ of Chaohu can be attributed to the administrative adjustment implemented by the Anhui province government. In 2011, the original prefecture-level city of Chaohu was split into three parts. One part (Juchao district) was renamed (new) Chaohu and was merged into Hefei City as a county-level city. That is, the current Chaohu is artificially designated as part of Hefei. Its ‘border breaking’, which appears in the generated regionalisation, is thus the product of administrative annexation.

- Restrictions of landforms on intercity connections

Table 6.3 presents the benchmarked intra-connectivity for the 15 landform regions. The main point to make here is that the plains and basins have stronger intra-connections than the regions dominated by hills and mountains. In particular, the Sunan Plain and the Southeast Coastal Plain have even stronger intra-connections than the average integration level of the generated sub-regions. It is important to remember that intra-connectivity is a relative measure, which is benchmarked by comparing it with the outward connectivity of the involved cities. Thus, the measure implies that plains and basins have more intra-connections than outward connections, while hilly and mountainous areas have more outward connections than intra-connections. In addition to the fact that plains/basins have relatively denser transport networks and the hills/mountains having relatively sparser networks, hilly and mountainous areas tend to have more connections with external cities, which help them to access larger markets and economic entities. However, the Zhenan Mountain region, in which Longquan and Lishui are located, is a major exception and has stronger intra-connectivity, which is the result of the strong administrative relationship between the cities.

Table 6.3. Benchmarking intra-connectivity (DI') for 15 landform regions

Rank	landform regions	DI'	Rank	landform regions	DI'
1	Sunan plain	1.87	9	Zhejiang plain	0.55
2	Southeast coastal plain	1.64	10	Jianghuai hills	0.40
3	Zhenan mountains	0.84	11	Jianghuai plain	0.36
4	Jinqu basin	0.79	12	Zhedong hills	0.34
5	East coastal plain	0.75	13	Wannan mountains	0.17
6	Huanghuai plain	0.71	14	Wanxi-Dabie mountains	0.07
7	Riverside plain	0.62	15	Zhexi hills	0.02
8	Huaibei plain	0.58			

- Restrictions of dialects on intercity connections

Table 6.4 presents the benchmarked intra-connectivity for four dialect regions and 10 sub-dialect regions. It can be observed that the sub-dialect regions have more intra-connectivity than the dialect regions. At the scale of the dialect regions, the

Central Plains Mandarin and Wu Chinese regions are the two most intra-connected regions. The high integration of the two dialect regions can be attributed to their unique geographic and economic positions in the YRD. The Central Plains Mandarin region, which is located at the YRD's northern edge, has closer connections to the Central Plains region in terms of culture and economy than with the other parts of the YRD. Additionally, the Wu Chinese region is indisputably the spatial and economic core region with closer intercity connections (the YRD was once viewed as equal to the Wu Chinese region in history, although the geographical scope of the YRD has largely extended beyond that geographic scope of the Wu Chinese region) (Wang and Sun, 2015). At the scale of the sub-dialect regions, the intra-connections of the Oujiang and Taizhou dialect regions are very evident. Their extremely strong intra-connectivity appears in the generated regionalisation as two individual clusters. These two dialects are the most mutually unintelligible languages compared with other varieties of Chinese. Partly because of the distinct dialects, the locals possess a strong sense of identity and form tight, trust-based social networks (Wei et al., 2007).

- Assessment of the intra-connectivity of the urban regions designated by CSLRPs

Many government-designated urban regions (by means of CSLRPs) are considered 'arbitrary groupings' of nearby metropolitan areas rather than entities that reflect the actual integration of urban regions (Liu et al., 2016). Table 6.5 (for CSLRP codes, see Appendix C in the end of the thesis) presents the benchmarked intra-connectivity for 11 designated urban regions. The most obvious pattern is that in which the intra-connectivity of all urban regions is less than in the average integration scenario of the generated sub-regions. That is, the degree of the regional integration of these regions is relatively weak, at least in terms of human intercity mobility. This view is consistent with Li and Wu's (2013, p. 145) argument in that 'the regional plan is manipulated by the local government to lobby for development rather than coordination'. We discuss these so-called 'arbitrary groupings' by investigating the process of grouping five Anhui province cities into the Central Plains Economic Region (CPER) – the least integrated urban region in Table 6.5.

The CPER was originally proposed by the Henan provincial government in search of a series of privileges conferred by the central government in areas such as tax, investment, and land utilisation. Meanwhile, the central government also intended to cultivate inland economic growth poles for balanced development and in response to the diminishing economic activity on the coast. Against this backdrop, the concept of CPER was written into China's 12th Five-Year Plan (2011-2015) in 2011 (available at http://www.gov.cn/2011lh/content_1825838.htm), through which the construction of the Henan-centred CPER is officially viewed as a national development strategy. However, the geographic scope of the CPER was not delineated at that stage. In the stage of plan formulation dominated by the National Development and Reform Commission (NDRC), the Anhui provincial government had actively applied to add its northern cities to this ambitious plan⁸. The considerations that lay behind the application is that North Anhui has been the less developed part of Anhui Province, and this problem became more serious after the release of Plan of the Industrial Transfer Demonstration Zone of the Wanjiang City Belt, through which cities in South Anhui received a significant amount of resources and opportunities for further development. The Anhui provincial government thus tried to balance intra-provincial development inequality by merging its northern cities into the CPER. Similarly, other neighbouring Provinces such as Shandong, Shanxi, and Hebei also actively applied to add their regions to this plan. As a result of the interest coordination among the different Provinces, the CPER scope was finally delineated to cover all of Henan and parts of the Anhui, Shandong and Shanxi Provinces, in which northern Anhui is entirely included. In conclusion, the delineated scope of CPER is more properly the product of a series of balances of administrative interests to reduce regional disparities rather than depending on the degree of regional integration.

Table 6.4. Benchmarked intra-connectivity (DI') for 4 dialect regions and 10 sub-dialect regions

Rank	Dialect zones	DI'	Rank	Sub-Dialect zones	DI'	Rank	Sub-Dialect zones	DI'
1	Central Plains Mandarin	0.44	1	Oujiang dialect	2.97	6	Shangfu dialect	0.49
2	Wu Chinese	0.34	2	Taizhou dialect	2.90	7	Tairu dialect	0.44
3	Jianghuai Chinese	0.20	3	Huangxiao dialect	1.26	8	Taihu dialect	0.43
4	Hui Chinese	0.17	4	Jinqu dialect	0.71	9	Shangli dialect	0.34
			5	Xuhuai dialect	0.62	10	Hongchao dialect	0.25

Table 6.5. Benchmarked intra-connectivity (DI') for 11 designated urban regions by CSLRPs

Rank	Central State-led Regional Plan	DI'	Rank	Central State-led Regional Plan	DI'
1	PWTSEZ	0.86	7	RPYRD	0.37
2	PSMDA	0.62	8	PDMRRD	0.31
3	PHUEC	0.58	9	RPNM	0.25
4	PITCDRSA	0.52	10	PZOEDDZ	0.22
5	PJCD	0.52	11	PCPER	0.22
6	PITDZWCB	0.40			

6.5 Discussion and conclusions

In this paper we investigated the regionalisation of the YRD from the perspective of human day-to-day intercity mobility. We conclude by discussing the key findings, some of which enhance our understanding of the YRD's formation, while others more generally relate to our understanding of the relation of 'network' and 'territory' in regional (re-)productions.

China's mega-city-regions are characterized by a range of spatial fragmentation processes in terms of physical, economic, cultural and administrative factors. Thus, the discussion of the generated regionalisation for the YRD is rooted in the particular context of China's regional and urban development. Our research first established that administrative borders – particularly provincial borders – strongly affect intercity connections. In addition, a small number of cities with strong economic performance, distinctive geographical and historical characteristics, and administrative annexation appear as 'cross-border' cities. We also discovered that the restrictions of rugged landform patterns and (unintelligible) dialects on regional integration remain significant. Moreover, by assessing the integrated degree of emerging regional (economic) alliances (created by multiple central state-led regional plans), we argued that the CSLRP regions are more or less the product of balancing administrative interests and thus have a relatively weak foundation for regional integration.

These empirical findings also invite reflection on regions caught between territory and networks (cf. Harrison, 2013). Based on the analyses of Weibo users' intercity mobility within the YRD, three observations can be made. First, we have shown that regional formations are bound through interconnected socio-economic activities. Second, the 'bounded' network organisations can be viewed as the product of the underlying territorially embedded spaces, albeit the effects of different physical, economic, cultural and administrative spaces on regional integration are distinct and interpenetrating. Third, historical paths of regional formation also play an important role in understanding regional relational configurations. This is evidenced by the fact that the overall patterns of the interaction-based regionalisation and the phenomenon of cross-border cities manifest underlying historical factors.

One policy implication of our research is based on the observation that, since the early 2000s, China has experienced a resurgence of domestic regionalism in the wider context of marketisation and decentralisation. Regional planning is increasingly proposed by multiple levels of government, and the construction of various regional alliances has become part and parcel of urban development strategy. In the ‘new type urbanisation strategy’ recently implemented by the central state, prompting the development of urban agglomerations is established as a normative objective of national spatial development. However, from the standpoint of local authorities, bundled development is not only a means to promote intercity cooperation and pursue agglomeration externalities but also a vehicle for massive infrastructure investment. It also implies governance recognition by the central state. As a result, local governments scramble to sponsor and/or join these regional alliances. This research reminds policy-makers that there is a need to rethink whether cities grouped during the wave of regional-alliance construction are in fact rooted in tangible intercity connections or only ‘a forced marriage’ for economic interests in reality. In addition, this research identifies a need for further research on how political barriers affect socio-economic flows in the Chinese context.

The research presented here has several limitations, which suggest methodological approaches for further research. One limitation relates to a concern for the representativeness of Weibo data. Although our data source has been widely recognized as producing valuable material for fine-grained geographical research, the data only include information provided by social media users. Recent studies suggest that the social media sampling of Facebook and Twitter is biased towards highly educated groups, urban dwellers and men (Hacklay, 2012; Li et al., 2013; Stephens, 2013; Hecht and Stephens, 2014). In our research, an age bias towards a younger group could be noted. However, whether these potential biases of social media data sampling result in bias with respect to the estimated patterns of overall human activity is unclear. Although we investigated the validity of Weibo-based mobility by comparing our data with overall population distribution data, to establish the representativeness of social media users finer-grained research is required. In addition, this specific comment is obviously part of a broader debate on the pitfalls of using big data in urban-geographical research (Poorthuis et al., 2016).

Finally, apart from the data concerns, the research focuses on the network of human day-to-day intercity movements, whereas it is clear that urban networks are multiplex phenomena (Burger et al., 2014). Therefore, the need to examine other types of linkages through further research is required.

Notes

1. In network science, a group of nodes that are more closely connected to one another than to the other nodes in their network is termed a ‘community’. For reasons of clarity, the clusters of cities generated by the community detection technique in this paper are referred to as communities.

2. ‘City’ has two different meanings in China’s urban system. One is a municipal unit that consists of urban districts and extensive counties and is literally translated as ‘*Shi*’. The other is an urbanized or metropolitan area, which approximately corresponds to the concept of ‘city’ in Europe and the United States. Such areas are literally translated as ‘*Chengshi*’. In this paper, ‘city’ refers to the municipal unit (for additional detail, see Chan, 2007). In addition, statutory cities in China consist of municipality-level cities, prefecture-level cities and county-level cities, and county-level cities are under the administrative jurisdiction of prefecture-level cities (for additional detail on China’s administrative divisions, see Ma, 2005).

3. Because our research object is cities, if a region has more than one landform, we unify physical landforms according to the landform of the urban centre. The partition according to dialects follows the same rule.

4. The official geographic scope of the Zhejiang Ocean Economic Development Demonstration Zone in Figure 6.1d does not include the counties in Hangzhou. This paper extended its scope to include the extensive counties of Hangzhou to maintain a consistent research scale.

5. The number of monthly active users registered within the YRD is calculated based on the data from the Weibo users annual statistical report of 2014 issued by Sina Corporation.

6. Newman-Girvan modularity is a quality measure of the community structure of networks. It is calculated by comparing the edge density within modules with the edge density in a random distribution with the same number of nodes (for additional detail, see Newman, 2006).

7. The range of modularity is from -1 to 1, with positive values indicating the presence of community structure. Values within the range of 0.3 to 0.7 are typically considered to signify a strong cluster structure.

8. ‘They (the North Anhui cities) had tried every possible means to make the cut (to be added into the CPER)’, a source with the Anhui Provincial Development and Reform Commission said in an interview with Xin’an Evening News (a mainstream newspaper in Anhui Province), cited from <http://english.anhuinews.com/system/2012/08/08/005133056.shtml>.

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7. Discussion and Conclusions

7.1 Overview of this dissertation

Despite the increased adoption of ‘network thinking’ in understanding urban/regional systems and the rapid development of mega-city regions in China, studies investigating the regional formation within China’s mega-city regions through the lens of ‘urban networks’ are still rather thin on the ground. Taking the Yangtze River Delta (YRD) as an example, this dissertation has aimed to gain insight into the regional formation – especially the organisation of intercity connections – of these emerging mega-city regions in China. Drawing on a mapping of multiplex urban networks in the YRD, this study has analysed their spatial patterns and corresponding explanatory factors, as well as assessing the polycentric development of this mega-city region.

In this concluding chapter, I will summarise the main findings of this research through providing answers to the three main research questions raised in the introductory chapter:

- 1) What are the spatial patterns of intercity connections within the YRD from the lens of multiple linkages?
- 2) Is the YRD a polycentric urban region?
- 3) What are the explanatory factors behind these spatial patterns?

Based on this, I will draw out some of the policy implications of this research by proposing a systematic assessment of the patterns of regional integration within mushrooming state-orchestrated urban clusters. This dissertation ends with a suggestion for possible avenues of future research.

7.2 Main findings of this dissertation

7.2.1 What are the spatial patterns of intercity connections within the YRD from the lens of multiple linkages?

Given the multiplexity of urban networks, in this dissertation I have mapped three kinds of urban networks to observe their spatial patterns. The spatial patterns of different networks share some commonalities, but also (re)present specific formations.

- The power-law distribution of cities' and city-dyads' connectivities and the notable barrier effect of provincial borders stand out as two commonalities with regard to the spatial patterns of different networks.

First, the initial observation is that only a small number of cities and city-dyads constitute the backbone of these networks. This is in line with two recurring phenomena in urban systems and network science: the power-law distribution of city size (Gabaix, 1999) and the scale-free feature of networks (Batty, 2008). In spite of this, the most connected cities and city-dyads within these networks vary considerably, which will be discussed in more detail later on. Second, the barrier effect of provincial borders is clearly visible. In the network of transport linkages, we observed that almost all of the most connected city-dyads are intra-provincial pairs (Chapters 2 and 5). The networks of business interactions and intercity mobility exhibit similar patterns (Chapters 3 and 5). Provincial boundaries in China reflect the homophily of cultural, social, and economic divisions on the one hand; and are related to corresponding political power and local institutions, which would facilitate or hinder intercity flows on the other hand. As a result, intercity connections across provincial boundaries are rarer than between cities within the same province. The notable effect of provincial boundaries in hindering intercity connections in China has recently been illustrated by investigating the geographical patterns of Chinese broken intercity trunk roads in Liu and Zhou (2017), in which broken trunk roads are more likely to occur between cities across provincial boundaries than between cities within the same province.

The distinctiveness of the spatial patterns of each of the networks can be found in varied rankings of the most connected cities and city-dyads, as well as the overall structure of networks. This distinctiveness can be summarized in two main findings:

- The different connectivities of cities and city-dyads in different networks reflect the differential relevance of the network-makers (i.e. agents) in the three types of networks.

First, the transit cities in main corridors, such as Suzhou, tend to occupy central positions in the transport network, and correspondingly the connections between neighbouring cities or between cities within the same transport corridor consist of

the backbone of the network of transport linkages (more precisely, the network of transport provisions). However, whether the high connectivity in the network of transport provisions necessarily implies a central role in the network of actual flows of passengers is open for discussion (Chapters 2 and 5).

Second, cities with tourist resources, such as Hangzhou, have higher connectivities in the mobility network than in other networks. Similarly, the strongest connections are, above all, between Shanghai and surrounding cities with well-developed tourism resources. However, this is perhaps related to a sampling issue in that social media check-ins are skewed toward leisure and tourism activities (Liu et al., 2014), as well as having an age bias towards younger groups. In addition, when investigating the largest connections for every city in a relative measure (i.e. removing the impact of cities' connectivities), the most connected city-pairs – with the exceptions of Shanghai-Suzhou and Ningbo-Zhoushan – are those between provincial capitals and their subordinate cities. This exemplifies how cities' administrative ranks shape the formations of intercity connections (Chapters 3 and 5).

Third, the central position of four provincial capital cities – Shanghai, Nanjing, Hangzhou, and Hefei – is more visible in the network of business interactions, and the connections between these capital cities constitute the backbone of the business network. This echoes the strong political undercurrents in shaping China's intercity connections. The key point to make here, however, is that political forces matter more for the intercity business linkages. This is because producer service firms tend to locate their regional headquarters in political centres to get access to preferential policies and local institutional arrangements (Chapters 4 and 5).

- The difference in the structure between the three networks reflects the nature of different network-makers on the one hand and the significant regional inequality within the YRD on the other hand.

Despite sharing a power-law distribution, the inequality of the distribution of city and city-dyad connectivities is obvious. The network structure of transport infrastructure linkages is relatively 'flatter' while the network structure of intercity mobility is relatively 'steeper'. On the one hand, the transport network in this

research reflects the provision of infrastructure that enables actual passenger flows, whose development is steered by authorities who need to consider not only accessing larger passenger-generating cities but also alleviating regional inequality. As a result, there is a mismatch between the connections of transport infrastructure and the flows of actual passengers, with the former being flatter than the latter (Chapters 2 and 5). On the other hand, the network of intercity mobility reflects the actual human movements, with a bias towards leisure and tourism activities, thus being in line with the significant regional inequality in terms of the distribution of population and economy, as well as tourism resources within the YRD (Chapters 3 and 5).

7.2.2 Is the YRD a polycentric urban region?

I (re)assessed the polycentric structure of the YRD by adopting different measures and examining them through different lenses of intercity connections (Chapters 2, 3, and 4). All of these empirical analyses point to a polycentric structure for the YRD. In particular, Chapter 3 suggests that the polycentricity of the YRD is considerably higher than that of a benchmarked rank-size distribution. Apart from verifying its polycentric structure, this dissertation focuses on different themes on the polycentric structure of the YRD, in which two particular findings stand out (Chapters 2 and 4).

- The network of transport provisions tends to be more balanced than the network of passenger flows it undergirds.

By investigating the rank-size distribution of cities' degree centralities, I compared the degree of 'flatness' (and therefore: balance) among centres – a particular indicator of polycentric development – in the transport provision network and the modelled network of passenger flows. The result shows that the network of transport provisions is more balanced than the modelled network of passenger flows. In other words, if one examines regional polycentric formations through the lens of transport infrastructure provision, it would produce a biased result towards a more polycentric structure (than the actual network of passenger flows it undergirds) (Chapter 2).

- The degree of its polycentricity decreases as the number of cities involved in the measurement increases with the drop-off being rather steep.

In this dissertation, I revisited the issue of the sensitivity of the ‘level’ of polycentricity to the choice of cities in quantitative measurements (Chapter 4). A test of the sensitivity of its polycentricity reveals that the degree of polycentricity decreases as the number of cities involved in the measurement increases, and the drop-off is rather steep. This displays the significant differentiation between the three central cities and other cities in shaping the polycentric structure of the YRD. In addition, this examination of sensitivity also identifies ‘main’ cities that contribute most to the ‘polycentricity’ of the YRD: three cities (Shanghai, Nanjing, and Hangzhou) are explicitly positioned as regional centres and these cities share a relatively balanced distribution in importance. This is in line with cities’ orientations assigned by central government in official documents. For instance, the YRD agglomeration development plan defined these cities as regional centres, in which Shanghai is assigned to undertake the role of ‘global city’, Nanjing (with its hinterland) is assigned to play the function of the regional financial, business services, and educational centre, and Hangzhou (with its hinterland) is designed to be one of the regional economic centres, with the focus on cultural creative industries and e-commerce.

7.2.3 What are the explanatory factors behind these spatial patterns?

This research has examined the determinants of the multiplex urban networks in the YRD, highlighting whether these determinants affect each of the networks differently. Several variables have been identified as potential indicators that enhance or hinder intercity connections, including distance, GDP, population, political levels, and four homophily factors (i.e. administrative borders, landform contiguity, cultural affinities, and economic alliances) (Chapters 5 and 6). Although each of these factors exhibits obvious correlations with intercity connectivities in the three networks – with the exception of the cultural affinities’ effect on the business network – only some of these explanatory factors decisively affect each of the three networks. The exception of cultural affinities can be attributed to the ‘multi-localational’ nature of producer service (PS) businesses. Unlike Chinese family enterprises, which are firmly embedded in a thick local cultural context, PS firms tend to set their branches in a broader territory to access ever-larger markets and to

protect their brand integrity, thus resulting in unbounded patterns associated with local cultural affinities.

With regards to the different determinants of the multiplex urban networks, the four major findings are as follows.

- The geography of intercity mobility is fundamentally shaped by Euclidean distance, while the effect of Euclidean distance on the business network is relatively weak.

The first finding is related to the effect of distance and spatial adjacency on intercity connections. This research shows that regional partitions based on intercity mobility are perfectly spatially adjacent. This is in line with Tobler's (1970) first law of geography, which theorised that connections between neighbouring geographical units tend to be more intensive. However, the point here is that the geography of intercity mobility is *fundamentally* shaped by spatial distance, as all city communities with close connections are characterised by complete spatial adjacency (Chapter 6). Nonetheless, the effect of spatial distance on the business network is evidenced to be relatively weak in comparison with other factors. This is because, as mentioned before, the PS firms tend to run their internal businesses across long distances. This, in turn, reminds us that distance is not an all-purpose parameter in simulating the network of business flows (Chapter 5).

- GDP decisively affects each of the three networks, while the effect of population seems to be specific to the mobility network.

Second, GDP and population, which are two commonly-used gravity-type factors in modelling urban networks, affect the three types of networks differently (Chapter 5). GDP has a strong effect on all three networks, while the effect of population is visible only in the mobility network. On the one hand, cities' economic abilities shape their attractiveness to business and human activity and facilitate transport infrastructure investments, while population size is more closely related to the volume of intercity mobility. On the other hand, the spatial distribution of economic and population size within the YRD are spatially mismatched; thus, population does

not appear to be a determinant in the transport infrastructure network and the business network.

- The role of cities' administrative-political levels in shaping these urban networks is evident, with pronounced effects on the business network.

The research suggests cities' administrative-political levels play a key role in shaping urban networks (Chapter 5). Because of China's party-state territorialisation practices (Cartier, 2015), cities' administrative rank always define their economic status, as well as fiscal and administrative power. As a result, cities with higher administrative rank tend to be hubs in infrastructure, mobility, and business networks. This is in line with the previous observation of the hub-and-spoke structure of the mobility network (Chapter 3) and the central position of four provincial capitals in the business network (Chapter 4). Meanwhile, the effect of political levels on the business network is more notable in that provincial capitals are the main foci of business flows (Chapter 5).

- With regard to the four homophily factors, notable patterns include the ingrained effect of administrative borders on all networks, the significant restrictions of landform patterns and dialects on intercity mobility, and the relatively weak intercity integration within emerging regional alliances.

First, and perhaps surprisingly, are the impediment administrative borders posed to intercity flows. Although so-called boundary control and regional protectionism have been considered to have been gradually undermined in contemporary China (such as the deregulation of the *hukou* registration system) (cf. Ma, 2005; Li and Wu, 2012), the inhibition of administrative borders (especially provincial borders) to intercity connections remains strong. This is clearly illustrated in the provincial borders-matched but interaction-based regionalisation (Chapter 6). The statistical analysis in Chapter 5 also confirms that the provincial borders strongly affect all three types of flows. Second, in spite of the development of information technology and transport infrastructure reducing the constraints of physical space and cultural segregation, the influence of landform and cultural affinities on intercity flows is still significant. In particular, rugged landform patterns and unintelligible dialects have greatly bounded intercity mobility (Chapter 6). Furthermore, this research also

documents that the legacies of landform contiguity are more visible for the intercity transport network *in comparison with* other networks and other homophily factors (Chapter 5). Last but not least, this research exposes that state-orchestrated regional alliances within the YRD are not per se closely connected. Although the development of regional alliances has been proposed and promoted, claiming to be in pursuit of regional cooperation, the degree of the regional integration of these alliances is relatively weak in comparison with the integration associated with landform and dialect regions (Chapters 5 and 6). This identifies the need for a thorough investigation on whether these mushrooming regional alliances in China are rooted in tangible intercity connections or are only ‘arbitrary groupings’ to lobby for development. This points to the main policy implications of this research, which will be discussed in the following section.

7.2.4 Methodological and theoretical contributions

Apart from these empirical findings, this dissertation also contributes to the literature on urban networks and regional studies methodologically. First, to bridge the gap between physical infrastructure networks and actual flows occurring in these networks, this research focuses on the example of rail networks and presents an alternative approach to approximating passenger flows in railway networks (Chapter 2). Second, to enrich available data sources reflecting intercity connections, this research shows the research potential of location-based social media (LBSM) data in mapping intercity flows of people (Chapter 3). Third, to tackle the issue of selecting cities in quantifying the polycentricity of urban regions, we introduce a stepwise framework for investigating different roles that cities play in shaping polycentric structures and subsequently identifying different mono- and polycentric structures of urban regions (Chapter 4). In addition, we also propose quantitative methods to compare different regionalisations, through which the link between different regional formations can be investigated (Chapter 6).

Theoretically, this dissertation also contributes to the conceptual debate on the coexistence of ‘networks’ and ‘territories’ in the (re)production of regions. Based on empirical analyses of intercity mobility within the YRD, this research has shown that regional formations are bound through ‘networking’ intercity activities, while

the network patterns are the product of underlying physical, economic, cultural and administrative spaces. The empirical analysis also displays that ‘historical paths of regional formation’ play an important role in understanding regional relational configurations. Moreover, other theoretical debates such as the multi-scalar and multiplex nature of urban networks have been involved in these empirical investigations (Chapter 6).

7.3 Policy implications of this research: towards an assessment of the patterns of regional integration within state-orchestrated urban clusters (*Chengshiqun*) in China

Although this research is useful toward understanding the geographies of the networked formation of mega-city regions in China, at least one key question arises: how might this research be useful to policy makers and urban planners? The answer to this question is given by re-thinking the recent wave of the construction of various urban clusters (*Chengshiqun*).

Since the early 2000s, China has been pursuing a new spatial form of organisation of political and economic operations, namely, the development of urban clusters (*Chengshiqun*). Similar to the emergence of ‘new city-regionalism’ in advanced capitalist economies (Scott, 2002; Ward and Jonas, 2004; Wu, 2016), the initiative of urban clusters echoes the dispersal process of economic activities from individual mega-cities to wider city regions in the context of globalisation and informatisation. As the initiative of building urban clusters is proposed to facilitate regional coordination and environmental sustainability, and access to the supposed benefits of agglomeration, it might be expected that urban clusters are orchestrated on the basis of regional integration. In the practices of policy making and regional planning, the orchestration of building urban clusters represents, however, a broad mix of other motivations: local governments scramble to join these regional alliances to pursue economic interests, such as massive infrastructure investment, while the central government attempts to reassert its power in regional governance and balance a series of local government interests, as well as reducing regional disparities. Consequently, it is questionable whether state-orchestrated urban clusters are in fact rooted in tangible intercity connections.

In this research, drawing on the assessment of intercity connectivities of and within the YRD, the relatively weak degree of regional integration in urban clusters has been confirmed. It reminds policy makers to re-think whether urban cluster construction does take full account of the basis of regional integration or rather a forced marriage for economic or political interests. Put simply, this identifies a need for an investigation of the processes underlying grouping cities into urban clusters and the related political interventions. Without such investigation, we are left with fuzzy knowledge as to whether a state-orchestrated urban cluster is a closely-connected geographic entity or only an administrative-dominated spatial assemblage. Without such knowledge, we may end up with ill-informed policies and improper infrastructure investment that are not used where it is most needed. Of course, this research also invokes caution in creating other new urban clusters. That is, the delineation of geographic scope of urban clusters should be premised on tangible regional integration.

7.4 Avenues for further research

This dissertation has aimed to contribute to our understanding of the regional formation of the YRD. Simultaneously, it also suggests a variety of avenues for future research. Apart from the appraisal of the regional integration within emerging urban clusters in China and the investigation of the processes of grouping cities into urban clusters, which have been mentioned before, I suggest four other major topics for further research.

First, generalising the case study of the YRD to other mega-city regions in China is needed. Although the YRD is an obvious example of a Chinese mega-city region, different mega-city regions – in spite of sharing commonality – may manifest different characteristics with regard to the number of cities, geographic scales, development stages, industrial patterns, administrative ranking, and the national/global roles of their leading cities. Different types of mega-city regions may thus exhibit different patterns of intercity connections. A comprehensive assessment of polycentric and networked patterns for various mega-city regions, therefore, is necessary for comprehensively understanding the development of mega-city regions

in China. With some exceptions (e.g. Song, 2014; Liu et al., 2016; Zhao et al., 2017), such studies have been lacking to date.

Second, this dissertation has assessed which factors affect the formation of intercity connections, but we know little about the exact process underlying these effects. For instance, administrative boundaries have been shown to be playing a fundamental role in shaping the patterns of intercity connections, but how the border ‘blocks’ intercity flows is unclear. Answers to such questions are significant for policy makers in order to formulate policies promoting regional integration. This is, therefore, an obvious avenue for future research.

Third, in spite of the popularity of urban network and polycentric development research in the literature, the potential economic and environmental implications of networked and polycentric development have been lacking substantial evidence (see, however, Meijers and Burger, 2010). A critical question has remained unanswered: is the polycentric/networked development of the YRD (and China’s other mega-city regions) economically more productive and environmentally sustainable (than non-polycentric/networked patterns of development)? An empirical examination of the economic and environmental implications of such regional formation of the YRD would be an obvious area for future research.

Finally, given the multi-scalar and multiplex nature of the urban network, it would be worthwhile to: (i) analyse the external relations of the YRD in national and global urban systems; and (ii) examine other types of intercity linkages.

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APPENDIX A: Landform contiguity, cultural affinities and economic alliances of cities within the YRD (Chapter 5)

City	Landform Contiguity	Cultural Affinities	Economic Alliances
Shanghai	Sunan Plain	Wu Chinese-Taihu Dialect	
Nanjing	Sunan Plain	Jianghuai Chinese-Hongchao Dialect	Sunan Modernisation Demonstration Region, Nanjing Metropolitan
Wuxi	Sunan Plain	Wu Chinese-Taihu Dialect	Sunan Modernisation Demonstration Region
Xuzhou	Huanghuai Plain	Central Plains Mandarin-Xuhuai Dialect	
Changzhou	Sunan Plain	Wu Chinese-Taihu Dialect	Sunan Modernisation Demonstration Region
Suzhou	Sunan Plain	Wu Chinese-Taihu Dialect	Sunan Modernisation Demonstration Region
Nantong	East Coastal Plain	Jianghuai Chinese-Tairu Dialect	Jiangsu Coastal Development Region
Lianyungang	Huanghuai Plain	Jianghuai Chinese-Hongchao Dialect	Jiangsu Coastal Development Region
Huaian	Huanghuai Plain	Jianghuai Chinese-Hongchao Dialect	Nanjing Metropolitan
Yancheng	Jianghuai Plain	Jianghuai Chinese-Hongchao Dialect	Jiangsu Coastal Development Region
Yangzhou	Jianghuai Plain	Jianghuai Chinese-Hongchao Dialect	Nanjing Metropolitan
Zhenjiang	Sunan Plain	Jianghuai Chinese-Hongchao Dialect	Sunan Modernisation Demonstration Region, Nanjing Metropolitan
Taizhou	Jianghuai Plain	Jianghuai Chinese-Tairu Dialect	
Suqian	Huanghuai	Central Plains Mandarin-Xuhuai	

	Plain	Dialect	
Hangzhou	Zhebei Plain	Wu Chinese-Taihu Dialect	Zhejiang Ocean Economic Region, Hangzhou Urban Economic Circle
Ningbo	Zhebei Plain	Wu Chinese-Taihu Dialect	Zhejiang Ocean Economic Region
Wenzhou	Southeast Coastal Plain	Wu Chinese-Oujiang Dialect	Zhejiang Ocean Economic Region, Western Taiwan Straits Economic Region
Jiaxing	Zhebei Plain	Wu Chinese-Taihu Dialect	Zhejiang Ocean Economic Region, Hangzhou Urban Economic Circle
Huzhou	Zhebei Plain	Wu Chinese-Taihu Dialect	Hangzhou Urban Economic Circle
Shaoxing	Zhebei Plain	Wu Chinese-Taihu Dialect	Zhejiang Ocean Economic Region, Hangzhou Urban Economic Circle
Jinhua	Jinqu Basin	Wu Chinese-Jinqu Dialect	
Quzhou	Jinqu Basin	Wu Chinese-Jinqu Dialect	Western Taiwan Straits Economic Region
Zhoushan	Zhebei Plain	Wu Chinese-Taihu Dialect	Zhejiang Ocean Economic Region
Taizhou	Zhedong Hills	Wu Chinese-Taizhou Dialect	Zhejiang Ocean Economic Region
Lishui	Zhenan Mountains	Wu Chinese-Shangli Dialect	Western Taiwan Straits Economic Region
Hefei	Jianghuai Hills	Jianghuai Chinese-Hongchao Dialect	Wanjiang City Belt
Wuhu	Riverside Plain	Jianghuai Chinese-Hongchao Dialect	Nanjing MetropolitanIndustrial, Wanjiang City Belt, Southern Anhui Tourism and Culture Region
Bengbu	Huaibei Plain	Central Plains Mandarin-Xinbeng Dialect	Central Plains Economic Region
Huainan	Jianghuai Hills	Jianghuai Chinese-Hongchao Dialect	

Ma'anshan	Riverside Plain	Jianghuai Chinese-Hongchao Dialect	Nanjing MetropolitanIndustrial, Wanjiang City Belt, Southern Anhui Tourism and Culture Region
Huaibei	Huaibei Plain	Central Plains Mandarin-Xuhuai Dialect	Central Plains Economic Region
Tongling	Riverside Plain	Jianghuai Chinese-Hongchao Dialect	Wanjiang City Belt, Southern Anhui Tourism and Culture Region
Anqing	Riverside Plain	Jianghuai Chinese-Huangxiao Dialect	Dabie Mountains Revolutionary Revitalisation & Development Region, Wanjiang City Belt, Southern Anhui Tourism and Culture Region
Huangshan	Wannan Mountains	Hui Chinese	Southern Anhui Tourism and Culture Region
Fuyang	Huaibei Plain	Central Plains Mandarin-Shangfu Dialect	Central Plains Economic Region
Bozhou	Huaibei Plain	Central Plains Mandarin-Shangfu Dialect	Central Plains Economic Region
Suzhou	Huaibei Plain	Central Plains Mandarin-Shangfu Dialect	Central Plains Economic Region
Chuzhou	Jianghuai Hills	Jianghuai Chinese-Hongchao Dialect	Nanjing Metropolitan, Wanjiang City Belt
Lu'an	Wanxi-Dabie Mountains	Jianghuai Chinese-Hongchao Dialect	Dabie Mountains Revolutionary Revitalisation & Development Region
Chizhou	Riverside Plain	Jianghuai Chinese-Hongchao Dialect	Wanjiang City Belt, Southern Anhui Tourism and Culture Region
Xuancheng	Riverside Plain	Jianghuai Chinese-Hongchao Dialect	Nanjing Metropolitan, Wanjiang City Belt, Southern Anhui Tourism and Culture Region

APPENDIX B: City codes (Chapter 6)

City	Code	City	Code	City	Code	City	Code	City	Code
Shanghai	SH	Haimen	HM	Hangzhou	HZ	Jinhua	JH	Ma'anshan	MAS
Nanjing	NJ	Lianyungang	LYG	Jiande	JD	Lanxi	LX	Huaipei	HB
Wuxi	WX	Huaian	HA	Fuyang	FUY	Yiwu	YW	Tongling	TL
Jiangyin	JY	Yancheng	YC	Ningbo	NB	Dongyang	DOY	Anqing	AQ
Yixing	YX	Dongtai	DT	Yuyao	YUY	Yongkang	YK	Tongcheng	TGC
Xuzhou	XZ	Dafeng	DF	Cixi	CX	Quzhou	QZ	Huangshan	HS
Xinyi	XY	Yangzhou	YZ	Fenghua	FH	Jiangshan	JGS	Fuyang	FY
Pizhou	PZ	Yizheng	YIZ	Wenzhou	WZ	Zhoushan	ZS	Jieshou	JS
Changzhou	CZ	Gaoyou	GY	Ruian	RA	Taizhou (Zhejiang)	TAZ	Bozhou	BZ
Liyang	LY	Zhenjiang	ZJ	Leqing	LQ	Linhai	LH	Suzhou (Anhui)	SUZ
Suzhou (Jiangsu)	SZ	Danyang	DY	Jiaxing	JX	Wenling	WL	Chuzhou	CUZ
Changshu	CS	Yangzhong	YGZ	Haining	HNG	Lishui	LS	Tianchang	TAC
Zhangjiagang	ZJG	Jurong	JR	Pinghu	PH	Longquan	LGQ	Mingguang	MG
Kunshan	KS	Taizhou (Jiangsu)	TZ	Tongxiang	TGX	Hefei	HF	Lu'an	LA
Taicang	TC	Xinghua	XH	Huzhou	HUZ	Chaohu	CH	Chizhou	CIZ
Nantong	NT	Taixing	TX	Shaoxing	SX	Wuhu	WH	Xuancheng	XC
Qidong	QD	Jingjiang	JJ	Zhuji	ZUJ	Bengbu	BB	Ningguo	NG
Rugao	RG	Suqian	SQ	Shengzhou	SGZ	Huainan	HN		

APPENDIX C: Central state-led regional plan codes (Chapter 6)

Central state-led regional plan	Code
Plan for Western Taiwan Straits Economic Zone	PWTSEZ
Plan for Sunan Modernisation Demonstration Area	PSMDA
Proposal for the pilot comprehensive reform on transformation and upgrading of Hangzhou urban economic circle	PHUEC
Plan for International Tourism and Culture Demonstration Region in Southern Anhui	PITCDRSA
Plan for Jiangsu Coastal Development	PJCD
Plan for Industrial Transfer Demonstration Zone of the Wanjiang City Belt	PITDZWCB
Regional Plan for the Yangtze River Delta	RPYRD
Plan for Dabie Mountains Revolutionary Revitalisation & Development	PDMRRD
Regional Plan for Nanjing Metropolitan	RPNM
Plan for Zhejiang Ocean Economic Development Demonstration Zone	PZOEDDZ
Plan for Central Plains Economic Region	PCPER

SUMMARY

Multiplex urban networks in the Yangtze River Delta: Spatial patterns and their explanatory factors

China's rapid urbanisation and economic growth are not evenly spread across its territory; rather, this growth has been focused in coastal provinces and a handful of mega-city regions. Understanding the geographies of these emerging mega-city regions thus provides a window into the formation of urban systems in China. Meanwhile, 'network thinking' has been increasingly adopted in understanding urban systems: mega-city regions are increasingly understood as a set of spatial relations between discrete and bounded cities. While the proliferation of research into 'intercity relations' has paved the way to understanding urban/regional systems in an era of globalisation and informationalisation, investigations into the urban networks underlying China's mega-city regions are still rather thin on the ground.

This dissertation aims to help filling this gap by offering a series of systematic, empirical analyses of the multiplex urban network formation within the Yangtze River Delta (YRD), arguably one of the archetypal mega-city regions in China. By mapping three kinds of intercity linkages – transport infrastructure links, business interactions and intercity mobility patterns – this dissertation aims to analyse their spatial patterns, assess how this relates to polycentric development, and explore the factors behind these patterns.

Although the spatial patterns of these different networks share some commonalities, such as the power-law distribution of city 'importance' and the notable barrier effect of provincial borders on intercity connections, their distinctiveness reflects the disparate relevance of the network-makers in the three types of networks. With regard to the most connected cities, the transit cities in main transport corridors, cities with tourist resources, and four provincial capital cities have higher connectivities – in comparison to other networks – in the transport network, the (leisure) mobility network, and the business network, respectively. With regard to the most connected city-dyads, the connections between neighbouring cities or between cities within the same transport corridor consist of the backbone of the transport network (more precisely, the network of transport provisions), while the

connections between Shanghai and surrounding cities with well-developed tourism resources occupy more important positions in the network of (leisure) mobility. The backbone of the business network, however, is constituted by the connections between four provincial capital cities. In addition, the network structure of transport infrastructure linkages is relatively 'flatter', while the network structure of intercity mobility is relatively 'steeper'. This can be attributed to two factors: (i) the development of transport infrastructure is steered by authorities who need to consider not only accessing larger passenger-generating cities but also alleviating regional inequality; and (ii) the network of intercity mobility reflects the actual human movements, with a bias towards leisure and tourism activities, thus being more in line with the significant regional inequality in terms of the distribution of population and economy, as well as tourism resources within the YRD.

By adopting different measures to assess the polycentric development of the YRD, this dissertation verifies its polycentric structure. Two particular findings stand out. First, the network of transport provisions tends to be more balanced than the network of passenger flows it undergirds. And second, the degree of its polycentricity decreases as the number of cities involved in the measurement increases with the drop-off being rather steep. This suggests the presence of significant differentiation between central cities and other cities in shaping the polycentric structure of the YRD.

This dissertation examines the determinants of the multiplex urban networks, with a particular focus on whether these determinants affect each of the networks differently. Eight potential factors that enhance or hinder intercity connections are examined, including distance, GDP, population, political levels, and four homophily factors (i.e. administrative borders, landform contiguity, cultural affinities, and economic alliances). Although each of these factors exhibits obvious correlations with intercity connectivities in the three networks – with the exception of the cultural affinities' effect on the business network – only some of these explanatory factors decisively affect each of the three networks. First, the geography of intercity mobility is fundamentally shaped by Euclidean distance, while the effect of Euclidean distance on the business network is relatively weak. Second, GDP and population affect the three types of networks differently: GDP has a strong effect on

all three networks, while the effect of population seems to be specific to the mobility network. Third, the role of cities' administrative-political levels in shaping these urban networks is evident, with pronounced effects on the business network. Fourth and finally, with regard to the four homophily factors, notable patterns include the ingrained effect of administrative borders on all networks, the significant restrictions of landform patterns and dialects on intercity mobility, and the relatively weak intercity integration within emerging regional alliances.

The investigation of the different networks' formation and their determinants is significant for policy makers when formulating policies promoting regional integration. Furthermore, this research identifies the need for an assessment of the patterns of regional integration within state-orchestrated urban clusters (*Chengshiqun*) in China. Although it might be expected that urban clusters are orchestrated on the basis of regional integration, the relatively weak degree of regional integration in urban clusters revealed in this research reminds policy makers to re-think whether urban cluster construction does take full account of the basis of regional integration rather than being a forced marriage reflecting particular economic and/or political interests.

SAMENVATTING

Meerevoudige stedelijke netwerken in de Yangtze River Delta: ruimtelijke patronen en verklarende factoren

China's snelle verstedelijking en economische groei voltrokken zich geografisch gezien erg ongelijk. Slechts enkele kustprovincies en een handvol 'mega-city regions' ontwikkelden en verstedelijkten de voorbije decennia in snel tempo. Een onderzoek naar de geografie en het functioneren van deze opkomende sterk verstedelijkte regio's laat toe om verstedelijkingsprocessen in China in de brede zin beter te begrijpen. Deze stedelijke systemen worden in toenemende mate vanuit een netwerkperspectief benaderd en onderzocht; een aanpak die de analyse van ruimtelijke relaties tussen steden impliceert. Hoewel de toename in dergelijk onderzoek naar interstedelijke relaties een beter licht werpt op het functioneren van stedelijke en regionale systemen in een geglobaliseerde wereld, blijven analyses van stedelijke netwerken in China's 'mega-city regions' schaars.

Teneinde dit hiaat te verkleinen ontwikkelt dit proefschrift een reeks systematische en empirische analyses van drie verschillende functionele stedelijke netwerken in de Yangtze River Delta (YRD), een van de meest archetypische Chinese 'mega-city regions'. De drie types interstedelijke links bestaan uit transportinfrastructuur, zakelijke interacties en mobiliteitspatronen. Hun geografie en polycentriciteit worden in kaart gebracht en geanalyseerd, alsook de verklarende factoren achter deze geobserveerde patronen.

Hoewel de ruimtelijke patronen van deze verschillende types netwerken gemeenschappelijke kenmerken hebben (zoals een 'power law'-verdeling tussen steden en het beduidende grenseffect van provinciale grenzen op interstedelijke verbindingen), reflecteert hun onderlinge verscheidenheid tegelijk de relevantie van de bevindingen voor netwerk-makers in de drie types netwerken. De meest geconnecteerde steden binnen de netwerken van transportinfrastructuur, zakelijke relaties en mobiliteit zijn respectievelijk: de transit steden langsheen de belangrijkste transportcorridors, steden gekenmerkt door een hoge mate van toerisme en de vier provinciehoofdsteden. De meest geconnecteerde stedenparen binnen de netwerken van transportinfrastructuur bestaan uit de steden langsheen dezelfde

transportcorridor, terwijl de belangrijkste interstedelijke relaties in het mobiliteitsnetwerk voornamelijk geobserveerd worden voor Shanghai en omliggende steden. De ruggengraat van het zakelijk netwerk bestaat daarentegen voornamelijk uit de interacties tussen vier provinciehoofdsteden.

Bovendien is de ‘power law’ verdeling van de netwerkstructuur van de transportvoorzieningen relatief ‘vlak’, terwijl die voor de interstedelijke mobiliteit relatief ‘steil’ is. Dit kan verklaard worden door twee factoren: (i) de ontwikkeling van transportinfrastructuur wordt gestuurd door autoriteiten die naast een focus op verbindingen tussen de grootste steden ook de socio-economische ongelijkheid in de regio moeten aanpakken door deze te ontsluiten; en (ii) het netwerk van interstedelijke mobiliteit weerspiegelt de eigenlijke menselijke mobiliteit, met een sturing in de richting van vrijetijdsactiviteiten en toerisme (hetgeen meer in lijn ligt met de significante regionale ongelijkheid in termen van verdeling van de bevolking, de economie en toeristische voorzieningen).

Voorts werd aan de hand van verschillende benaderingen de polycentrische ontwikkeling van de YRD onderzocht. Twee bevindingen zijn met name belangrijk: (i) het netwerk van transportvoorzieningen is meer in balans in vergelijking met het netwerk van passagiersstromen; en (ii) de mate van polycentriciteit neemt af wanneer het aantal steden betrokken in de berekeningen toeneemt (de ‘drop-off’ is hierbij eerder steil). Dit laatste suggereert de aanwezigheid van een beduidend verschil in belang tussen centrale steden en andere steden in het vormgeven van de polycentrische structuur van de YRD.

Deze dissertatie analyseert verder ook de verklarende factoren voor de al dan niet totstandkoming en bestendiging van stedelijke netwerken in de YRD. Acht mogelijke factoren die interstedelijke interacties stimuleren of verhinderen werden bestudeerd, waaronder Euclidische afstand, economische output, bevolking, politieke aspecten en vier ‘homophily’ factoren (m.n.. administratieve grenzen, contiguiteit in landvorm, culturele affiniteit en economische partnerschappen). Hoewel elk van deze factoren evidente correlaties vertoont met de interstedelijke connectiviteit in deze drie netwerken (met uitzondering van de invloed die culturele affiniteit uitoefent op het zakelijke netwerk), beïnvloeden slechts enkele factoren de

drie netwerken in sterke mate. Allereerst wordt de geografie van interstedelijke mobiliteit voornamelijk bepaald door Euclidische afstand, terwijl het effect van Euclidische afstand op het zakelijk netwerk relatief zwak is. Ten tweede beïnvloeden economische output en bevolking deze drie types netwerken op verschillende wijze: economische output heeft een sterk effect op alle drie de netwerken, terwijl het effect van bevolking specifiek lijkt te zijn voor het netwerk interstedelijke mobiliteit. Ten derde is de rol van de administratieve stedelijke schaal in de vormgeving van deze stedelijke netwerken evident, met uitgesproken effecten op het zakelijke netwerk. Tot slot zijn noemenswaardige patronen met betrekking tot de vier 'homophily' factoren het ingewortelde effect van administratieve grenzen op alle netwerken, de beduidende beperkingen van landvormen en hun interactie op interstedelijke mobiliteit, en de relatief zwakke interstedelijke integratie van opkomende regionale partnerschappen.

Voorliggende analyse van de ontwikkeling van verschillende types stedelijke netwerken en hun determinanten is essentieel voor beleidsmakers werkzaam op het gebied van regionale integratie. Bovendien toont dit onderzoek de noodzaak aan voor een analyse van de patronen van regionale integratie binnen staatsgeleide stedelijke clusters (*Chengshiqun*) in China. Hoewel verwacht zou kunnen worden dat stedelijke clusters momenteel gecoördineerd worden op basis van regionale integratie, toont dit onderzoek op basis van een zwakke mate van regionale integratie in de YRD aan dat deze vooronderstelling niet noodzakelijk opgaat. Op basis van voorliggend proefschrift lijkt het schaalniveau van de stedelijke cluster ontoereikend voor regionale beleidsvoering en bestendigt het boven alles voornamelijk economische en/of politieke belangen.