POLYCENTRIC DEVELOPMENT AND TRANSPORT NETWORK IN CHINA'S MEGAREGIONS

A Dissertation
Presented to
The Academic Faculty

By

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In Partial Fulfillment
Of the Requirements for the Degree
Doctor of Philosophy in City and Regional Planning

Georgia Institute of Technology

May 2014

Polycentric Development and Transport Network in China's Megaregions

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Date Approved: November 1st, 2013

ACKNOWLEDGEMENTS

I would like to thank my advisors, Dr. Steve French and Dr. Jiawen Yang. Dr. French always encouraged me and this dissertation would not have been possible without his advice and support. Dr. Yang led me to question my assumptions and clarify my thinking. Through his efforts, I became a capable, independent scholar. I am also indebted to my dissertation committee members, Dr. Bruce Stiftel, Dr. William Drummond, and Dr. Patrick McCarthy, for their superb expertise and guidance. I also wish to thank all the faculty members in the city and regional planning program, for providing the best education and research environment.

Most of all, I am grateful to my family and friends for their love and support of my academic endeavors.

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SUMMARY

China's mega-regions, in addition to cities and metropolitan areas, have become the engines for economic development, and the target areas for regional and national policies. Reflecting upon China's current path of regional urbanization, the proposed research examines a fundamental issue for China's megaregional development: the impact of transport network development on the spatial pattern of China's megaregions. Using the multiple national Censuses (1982, 1990, 2000, 2010) and the transport network GIS data in the corresponding years, this research 1) constructs measures of megaregional spatial patterns, 2) assesses the spatial trajectory of megaregional growth based on the differentiated growth rates of metropolitan cities, 3) computes indicators of megaregional transport network connectivity and accessibility, 4) examines the impacts of transportation infrastructure on megaregional growth trajectory.

This research helps understand the spatial structure of China's megaregions with newly constructed quantitative measures of polycentric spatial development, as well as the intra-megaregion and inter-megaregion variation of transport network in China. It also clarifies the link between transport infrastructure and megaregional spatial structure in China's unique context by providing quantitative evaluation of the implications of transport investment for the spatial pattern in Chinese megaregions. Finally it enriches the megaregional solutions to China's vision of economic, social and environmental sustainability.

CHAPTER 1. INTRODUCTION

1.1. Research Background

The past two or three decades have seen the rise of a new urban unit – megaregion. Internationally, mega-regions, in addition to cities and metropolitan areas, become the economic engines for economic development, and the target areas for regional and national policies. Megaregion is recognized not only in advanced territories such as the United States or Europe. In China, the National Development and Reform Commission identified 10 emerging megaregions and each megaregion spans multiple cities and even provinces.

1.1.1. Megaregion as a new framework in China

Large concentrations of population, resources and industries in major cities are a prominent feature in modern China. These cities function as pivotal nodes, around which cities of different scales come together to form new spatial configurations, where flows of people, capital, good and information have been increasingly strengthened.

Considering China's political contexts, cities within the same province tend to have stronger connections, and to some extent megaregaional boundaries overlap with provincial boundaries. However, spatial proximity, although relevant, is not the dominant factor for interconnection and networking; instead, professional, institutional and political competencies are usually more prominent (Groth & Smidt-Jensen, 2007). With China's transition to a market economy, complementary economic functions and industrial

specializations are more important factors in facilitating regional connections and developing new agglomerative spatial patterns. In addition, recent transport infrastructure investments in China further extend the radius for economic connections and interactions for cities. Therefore, the connections between cities may extend beyond provincial boundaries, while at the same time not all cities within same province have established strong connections.

These connections and interplays necessitate a new appropriate framework of urban analysis, which takes into account the increasing bonding in terms of population, labor market, transportation infrastructure and economic growth. Mega-region has emerged as the new, natural economic unit (Florida, Gulden, & Mellander, 2008b). Megaregional boundaries do not follow established administrative boundaries, and the definition of megaregional boundaries takes into account the established and developing connections, in terms of economic, social, political and environmental relationships. Thus urban analysis at the megaregional level fulfills the rising need.

In China, apart from the three highly-developed giant megaregions – Capital Economic Zone, Pearl River Delta and Yangtze River Delta, which account for a large share of the country's economic output, several other inland mega-regions are also emerging and developing. These 10 mega-regions cover around 20% of the total area of China. More than half of national population (census 2000 data) and 52% of GDP concentrated in these mega-regions. In addition, these megaregions will also be the main destinations for future national capital investment (Fang, 2012).

Megaregion provides a new scale and framework for achieving regional coherence. Megaregional planning actions and collaborative planning efforts have already been proposed and started. For example, in recent year, three megaregions have been designated as the Comprehensive Reform Pilot Regions:

- In 2007, Chuanyu megaregion was designated as the Comprehensive Reform Pilot Region for Urban-Rural Integration. The regional development of Chuanyu megaregion is suffering severely from its dichotomy between urban and rural disparities, and this initiative aims to achieve a more balanced regional development pattern.
- In 2008, Wuhan megaregion was designated by National Development and Reform Commission as the Comprehensive Reform Pilot Region for Energy-saving and Environment-friendly Development. The region's central location in China, low cost of living, natural resources, highly connected transportation network and competitive innovation and technology base have helped make it the "Sunbelt" in China.
- Liaoning megaregion has become the "rust belt" of China, and is burdened with a disproportionate share of outdated state-owned enterprises. In 2010, Liaoning megaregion was designated as the Comprehensive Reform Pilot Region for Innovative Industrialization, aiming to achieve regional industrial revitalization and sustainable restructuring.

The designation of these megaregions as the Comprehensive Reform Pilot Regions signifies the central government's recognition of megaregional planning as an emerging framework for addressing regional issues. The concept of mega-regional planning is

being discussed and experimented, and mega-regional planning actions have been implemented.

1.1.2. The imperativeness of polycentric population spatial patterns

Why polycentric

There has been wide discussion of how to plan the cities and regions differently in order to sustain life quality while accommodating urbanization (J. Yang, Shen, Shen, & He, 2011). The concept of polycentric development has gained widespread currency in planning and territorial development strategies. A polycentric and more balanced system of metropolitan city regions is not just a descriptive term, but also a means to promote and equalize economic growth (Hague & Kirk, 2003). A polycentric development can contribute to regional cohesion through dispersal of resources and economic activities into areas outside the core. Within a polycentric network, cities are complementary and they share beneficial linkages.

Polycentric spatial development is at the core of the European Spatial Development Perspective (European Commission, 1999a), it is identified as an essential response to help avoid further excessive economic and demographic concentration in the core areas of the EU, and to fully realize the economic potentials of all regions of the EU. Polycentric is perceived to be associated with principles of "equity, cohesion and sustainable development" (Cattan, 2007). A polycentrism approach to regional development promoted the development of many medium-sized urban centers rather than just a few large cities (Groth & Smidt-Jensen, 2007). Promoting polycentric development

is in line with Rawls's equity principle, in so far as well-being of the least advantaged groups are prioritized first (Baudelle, 2007).

Polycentricity can on the one hand retain the benefits from agglomeration and economies of scale, while on the other hand avoid the diseconomies associated with the excessive concentration of resources in the dominating megacities. A enhanced polycentric arrangement, well distributed throughout the territory and comprising a network of accessible metropolitan regions and their linked hinterland will improve access for secondary cities and the peripheral areas, and to improve economic connections and spatial balance for the entire territory (European Commission, 1999b, p. 20).

China's imperative situation

Population is the fundamental topic for urban studies. The spatial clustering and patterns of population has become an imperative issue for Chinese cities. The first decade of the 21st century has seen the exacerbation of the concentration of population and economic activities in a few core metropolitan areas in China, and China's urbanization has cultivated megacities with over 10 million population, such as Beijing, Shanghai, Guangzhou and Shenzhen. Those cities feature a heavy concentration of population and economic activities in a dense and crowded urban settlement (Song & Yang, 2011).

Historic statistics of population and GDP at the metropolitan level further illustrate the imperativeness of this issue. The average annual population growth rates and GDP growth rates of the 238 cities in China from 1982 to 2010 were collected and analyzed. A pooled correlation analysis of the five time periods (1982-1991, 1991-1995, 1995-2000,

2000-2005, and 2005-2010) generates a positively significant Pearson Correlation of 0.2751 ($p<0.001$). However, looking at the relationship between population growth rate and GDP growth rate in more detail reveals that the relationship is not a single-directional simple positive correlation (Table 1-1). During the first four sub-periods (1982-2005), the Pearson Correlation indexes between population growth rate and GDP population growth rate are around 0.5, all significant at the 0.001 level. However, during the period 2005-2010, the correlation between population growth and GDP growth is negatively significant, with the Pearson Correlation coefficient of -0.427 ($p<0.001$). Together with other urban phenomena, it indicates that the stage of diseconomies of development has been reached during the latter half of the 2000's.

Table 1-2 shows the differentiated correlation results for different types of cities, which as classified by their population density and GDP per capita level. It indicates that for cities with population density higher than the national average, or cities with GDP per capita higher than the national average, the negative correlation during the period 2005-2010 between population growth rates and GDP growth rates is stronger.

Table 1-1 Correlation between average annual population growth rate and GDP growth rate

Period	Pearson Correlation coefficient	pval
1982-1991	0.5076	0.0000
1991-1995	0.4687	0.0000
1995-2000	0.5445	0.0000
2000-2005	0.5278	0.0000
2005-2010	-0.4272	0.0000
All periods	0.2751	0.0000

Table 1-2 Corr elation between average annual population growth rate and GDP growth rate during 2005 - 2010

Period 2005-2010	Pearson Correlation coefficient	pval
By population density:		
Below mean	-0.1604	0.076
Above mean	-0.6017	0.000
By GDP per capita:		
Below mean	-0.2307	0.006
Above mean	-0.5448	0.000

In fact, the issues of large versus small cities rose since the late 1980s. China's City Planning Law which was adopted in 1989 states the national principle on city size: "to strictly control the size of large cities (with non-agricultural population of 500, 000 or more in its urban and inner suburban districts), rationally develop medium-sized cities (500 000 to 200 000 persons), and vigorously promote small cities (less than 200 000 persons) to an appropriate extent in the interest of a rational distribution of productive forces and of the population (People's Republic of China, 1989). However, this policy has never been effectively implemented (Lin, 2004). In fact, many of the following national policies are contrary to this objective. In addition, the household registration system

(hukou) has lost its main function of controlling population migrations from rural to urban areas and from less developed areas to more developed areas (Zhou & Ma, 2000, p. 253).

The increasingly severe traffic congestion, deteriorating environment quality, rising land rent and living cost signifies the rise of diseconomies of agglomeration in these metropolitan areas. Some of the major cities have witnessed the rising challenges of water or electricity shortage. Therefore fostering a more balanced polycentric spatial system at the mega-regional level has significant policy implications.

1.1.3. Why mega-regional transport network?

In 1980, half of China' population was classified as absolutely poor; but this large poor country has experienced economic growth rates in significant excess of the growth rates experienced by most countries that were richer than China (Bhalla, 2002, p. 184). Transportation infrastructure improvement is one the key reasons that contribute to this rapid growth, while at the same time a product of rapid economic growth.

As mentioned before, a large share of China's economic growth was concentrated in a few regions, which have developed into or have been evolving into megaregions. These areas have received tremendous investment and political support in various forms. It is also those megaregions that have seen a big number of large-scale transportation infrastructure constructions going on, which stimulate economic growth further.

In order to grow into truly functioning polycentric networks, cities and towns must be well connected to each other as a truly functional network, and transport connection is a

vital factor. Recent and projected transportation and communication infrastructure systems are further enhancing the important social, economic, and environmental links between the many parts within mega-regions (Center for Quality Growth and Regional Development 2006).

In the EU, the Trans-European Transport Network (TEN-T) was proposed in 1993, aiming to improve economic and social cohesion, by linking isolated and peripheral regions with the Union's more central regions, through “interconnecting and interoperable national networks by land, air, sea and inland waterways” (European Commission, 2007). In 2004, the EU identified 30 transnational axes, aiming to offer substantial reductions in journey times, and provide improved connections through additional capacity and improved quality of services.

In China, in addition to the traditional transportation modes, high-speed railway, highway, airports networks have been built up to establish faster and greater-capacity links between megaregions and within megaregion. For example, in Wuhan Megaregion, the objective of a “2 hour commute radius” from Wuhan to other cities in the same megaregion has been materialized, and the “one hour commute radius” goal for megaregion transportation planning is to be achieved in the near future. This plan involves the construction of new highways and bridges, upgrading of conventional rail lines and motorways, and upgrading and extension of existing urban rail system. In Liaoning megaregion, a 400 kilometer highway system connecting cities within it is being constructed, and some sections have already been open; public transit services (bus and urban rail) connecting the core city – Shenyang, and other cities within it have also

been strengthened. For megaregions, the completion of mega-regional transport systems will strengthen connections between cities of the region and cut travel costs between cities (J. Yang, Ross, Fang, & Song, 2011).

However, the statement of the possible benefits of transportation infrastructure for achieving a more balanced and sustainable regional pattern has not been substantiated with rigorous research. There exist the risks of 'pump effect' and 'tunnel effect': the improved connectivity through high-speed/high-capacity transport infrastructure may remove resources from the structurally weaker disadvantaged areas, or the peripheral areas are crossed without being connected (European Commission, 1999a).

The implications of transport infrastructure for the spatial pattern of megaregions need to be carefully examined and reflected upon to inform future policy decisions. Investments in transport infrastructure in China are still concentrated in railway and road – 28.6% for railway and 45.4% for road in 2009, and only a small part was invested in urban, air and water transport (Mu & de Jong, 2012). Therefore this research will study these two major modes of transport: railway and road.

1.2. Research Objectives and Questions

This proposed research takes the above research and planning challenges. The objectives of this research can be briefly summarized below:

a. To empirically examine megaregions' spatial patterns of demographic distribution at multiple time points.

b. To investigate in what ways transport investments have impacted the demographic spatial pattern and growth in Chinese megaregions.
c. To identify and explore transport investment strategies that can lead to a more balanced spatial pattern for China's highly polarized megaregions.

While the research is organized around one broad issue – the implications of transportation investment for the spatial pattern of megaregions, three specific questions will be asked under this broad issue:

a. How polycentric are China's megaregions? Have the megaregions become more polycentric or not?
b. Does transport investment significantly impact megaregional demographic spatial pattern? If so, in what direction and magnitude.
c. What adjustment in transportation planning and policies can help fostering a more polycentric megaregional spatial pattern?

The three questions match the above three objectives. Among these questions, question b is central to this evidence-based policy research. The multi-year assessment of megaregional spatial structure (question a) provides necessary information input for question b. Answers to question b partially imply answers to question c, and additional policy analysis will be conducted in order to reach reasonable policy recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1. Definition of megaregion and the rise of megaregion

Gottmann (1957) first coined the term Megalopolis to describe the almost continuous stretch of urban and suburban areas from Boston to Washington, the main NE-SW axis of which was about 600 miles long, and within the frame of which dwelt some 30 million people in 1950. This geography of the distribution of habitat is characterized by the coalescence of a chain of metropolitan areas, each of which grew around a substantial urban nucleus. Gottmann's work was enormously influential and, because of his work, the super-metropolitan character and the huge growth associated with megalopolis become a focus of urban studies.

Today, the United States and its economy can both be characterized as metropolitan. America's 363 metropolitan areas – complex regions of interwoven cities and suburbs – are home to more than eight in ten Americans and jobs (Brookings, 2007). Metro areas are the locus of the four drivers of national prosperity: innovation, human capital, infrastructure, and quality places (Brookings, 2008).

The increasingly linked metropolitan areas and the increasingly decentralized nature of the U.S. economy led the Regional Plan Association to promote megaregion as a key framework for economic analysis and urban policies. Megaregions are extended networks of metropolitan centers and the surrounding areas that include layers of relationships in environmental systems, infrastructure systems, economic linkages, settlement pattern and

land use, and shared culture and history (Center for Quality Growth and Regional Development 2006; Regional Plan Association, 2006). In the US, 10 megaregions have been proposed by the Regional Plan Association (Regional Plan Association, 2006). Most of the rapid population growth, and an even larger share of its economic expansion, is expected to occur in these 10 or more emerging megaregions (Center for Quality Growth and Regional Development 2006; Regional Plan Association, 2006). Similar megaregions have been identified in EU. Europe's largest megaregion spans Amsterdam-Rotterdam, Ruhr-Cologne, Brussels-Antwerp and Lille. Other megaregions are also identified, including the British megaregion, the Italian megaregion, Greater Paris and the Euro-Sunbelt megaregion (Florida, Gulden, & Mellander, 2008a).

Hall and Pain defined Megaregion as "a series of anything between 10 and 50 cities and towns, physically separate but functionally networked, clustered around one or more larger central cities, and drawing enormous economic strength from a new functional division of labor" (Hall & Pain, 2006a). Component cities and their hinterlands within megaregions are bounded by their economic, social, political and environmental ties, bringing the benefits of economies of scale, increased efficiencies, and enhanced connectivity (UN-HABITAT, 2012, pp. 31-32). A very important advance that the concept of 'megaregion' brings into our understanding about network relationship between cities is a fundamental shift of emphasis from attributes to flows, which captures the interdependencies between constituent cities of the entire system (Hall & Pain, 2006a; Taylor, 2004, 2005).

2.2. Agglomeration economy

This section examines fundamental agglomeration theories related to the emergence and growth of mega-regions. Mega-region, as the new, natural economic unit, emerges as metropolitan areas not only grow upward and become denser but also grow outward and into one another. From this perspective, mega-regions are not only agglomeration of industries and economic activities, but also agglomeration of metropolitan areas with integrated labor markets, infrastructure, and economic interrelations. Agglomeration economy is the key factor behind the growth of metropolitan areas into mega-regions. The specific advantages of the megaregional scale 'consist of and arise from the coexistence of multiple types of agglomeration economies within one regional space', which is 'sufficiently large and diverse so as to accommodate a far broader range of types of agglomeration economies' than any single metropolitan area typically does (Sassen, 2007).

Of course the concept of agglomeration is itself not new. Marshall (1890) was one of the first economists to stress the positive effects for firms from locating near each other. He recognizes three chief advantages of production on a large scale, namely economy of skill, economy of machinery and economy of materials. Another scheme for analyzing agglomeration economies was outlined by Ohlin (1933). Ohlin distinguished agglomeration economies arising from the size of local industry and that arising from the size of the local economy. A similar contribution to this field was made by Hoover (1937). He identifies three distinct influences on local production: large-scale economies within a firm, localization economies for firms in a single industry locating at the same

location, and urbanization economies for firms in different industries locating at the same location. In his formulation, internal returns to scale are firm specific, localization economies are industry specific and urbanization economies are urban region specific.

Hirschman (1958) introduces the two inducement mechanisms: backward linkage effects and forward linkage effects. Satellite industries, established through backward or forward linkages with master industries, enjoy the strong locational advantage from proximity to the master industry. He also points out that, the linkage effects of two industries in combination, which is larger than the sum of the linkage effects of each industry in isolation, helps to account for the cumulative character of development.

Isard (1998) extends this discussion from manufacturing industries to contemporary service trades. He illustrates the importance of localization, urbanization and other economies for both manufacturing industry and service trades. The location of service trades follows the same general principles of accessibility to input and market, scale of operations, and agglomeration economies and diseconomies as does the location of manufacturing industries. Location cost differentials will lead to either isolated or clustered spatial patterns, decided by the different characteristics of various industries.

At the early stages of urban development, agglomeration is the dominating force. Agglomeration economies occur, when industries and economic activities are located near each other. Thus, in order to reduce costs, industries tend to cluster together. With the modern trends of construction of transportation infrastructures, decrease of cost in transportation, advance of technology, the spatial patterns of modern urban areas have some new features. Advances of information technologies facilitated the geographical

dispersal of economic activities, while external agglomeration diseconomies arose in central urban areas, including traffic congestion, poor living environments and high land rent. It is widely argued that agglomeration has become less significant, and may eventually become obsolete. To some extent, employment and population have been increasingly decentralized across a wider region.

However, the general principles of agglomeration identified by economists since Marshall are still applicable in contemporary urban environments. Globalization raised the scale and complexity of economic activities and the economic connections between regions. Cultivation of resources, evaluation of intangibles, and delicate negotiation which can only be conducted through personal, face-to-face contacts, all exercise a tremendous pressure toward spatial concentration (Alonso, 1968, p. 627). Another reason is that, while spatial transaction costs have fallen dramatically across a wide front in recent decades, allowing many firms ready access to global markets, there still remain important kinds of transactions that are extremely sensitive to the effects of distance (Scott, 1996). Therefore, producers, firms and industries still need and are willing to agglomerate together in geographic space to secure the external economies developed in the interaction networks and share various benefits of agglomeration.

2.3. Spatial pattern of megaregions

As a city is composed of separate neighborhoods, and as a metropolitan region is made up of a central city and its suburbs, a mega-region is a polycentric agglomeration of cities

and their lower-density hinterlands. Drawing upon Christaller and Losch's central place theory, this section will explore the spatial hierarchy and structure of mega-regions.

The Central Place Theory was conceived, primarily by Christaller and Lösch, in order to explain the size and number of settlements, and the spatial organizational structure. Based on a study of the urban settlement patterns of Southern Germany, Christaller (1966) advanced the central place theory to model the spatial pattern of settlements using geometric shapes. A central place is a distribution center of good and services to its complementary region. Centrality is defined as the relative importance of a place with regard to the region surrounding it, or the degree to which the town exercises central functions. On the basis of the range of the central goods, Christaller developed the market principle, the goal of which is to serve a maximum number of consumers from a minimum number of centers, whereby places of different orders of centrality arrange themselves in a hierarchy. In this model, the central places are distributed over the region according to certain laws. Surrounding a greater central place are a wreath of smaller central places. Considering traffic factors, Christaller proposed the traffic principle, which minimizes the network length and economic transportation costs. He also proposed a sociopolitical principle from a political or administrative point of view, whereby the lower level places are completely controlled by the higher level centers.

Introducing the idea of a demand cone, Lösch (1954) focused on maximizing consumer welfare and creating an ideal economic landscape where the greatest number of locations coincide and transportation distances are minimized. Lösch identifies the equilibrium of economic, spatial and other forces that shape the spatial pattern of the economic

landscape together. Mills and Lav (1964) argue that free entry need not result in space-filling market areas with hexagons, and circular market areas and regular polygons with more than six sides are also possible. They reject the Lösch model further by arguing that free entry does not provide an efficient allocation of resources.

Mainly because of the limitations of theory assumptions, some critics are formulated against the central place theory, questioning the theory hypotheses and practicability. The applicability of the central place models in realistic situations may be limited, because of the failure to meet initial simplifying assumptions. It should also be noted that in realistic situations, the complicated urban patterns are shaped by various factors and mechanisms, and this calls for the integration of central place theory with other theories in the study of cities and regions.

Nonetheless, the theory maintains its strength in understanding the sizes and numbers of places, the relationship between functions of places and their ranks in urban hierarchy, and the spatial pattern of urban networks, especially in relatively homogeneous regions. According to the Central Place Theory, the system can be divided into five sizes of spaces: regional capital, city, medium-sized town, small town and country town. Within each mega-region, there are an extremely small number of regional capitals, which are places of the highest order, where the highest order of goods and services can be found. These regional capitals arise at locations, where a large number of market areas have their market centers in common, with all the advantages of a large local demand (Lösch, 1954, p. 124). There are a small number of places of a high order – cities with a somewhat great importance. There are large numbers of medium-sized towns – central

places with low orders, where the goods, services, functions provided by these places are not as diverse as cities of the higher hierarchy. We will find greater numbers of central places of lower order – small towns and country towns.

The size and the importance of a central place are strongly influenced by types of goods and levels of services offered at central places. The upper limit and lower limit of the range of a central good are very important concepts. A particular good or service cannot be purchased beyond the upper limit of this range, while lower limit decides the minimum scale required to offer a central good or service with any chances of profits. Therefore, a central place should provide goods and services according to its order in the region. In the globalizing economy, every city tries to attract some propulsive industries or development projects to boost local economies, but too ambitious development projects may not be feasible because the lower range-limit is beyond the economic capacity of the city. Within a mega-region system, central places with different orders should therefore provide goods and services and develop industries according to their orders or centralities in the system.

Sassen (1995 & 2007) has identified the new characteristics and trends of central places. National and global markets require new forms of territorial centralization and central places where the work of globalization gets done (Sassen, 2007). In addition, the process of globalization, symbolized by the increasing flow of labor, capital and commodity between regions and countries, leads to regionally dispersed network of operations. This dispersed network requires centralized control and servicing, and as a result we see in cities the formation of new urban economic cores mainly of banking and service

activities that come to replace the older typically manufacturing core (Sassen, 1995). Therefore, in the current global economy, although to some extent economic activities become spatially dispersed, centrality remains its ongoing importance in today's global economy with some new features.

2.4. China's regional development - The need for polycentric development

This section provides an extensive review of existing literature and review of China's regional development, and further states the necessity and importance of this research.

2.4.1. China's regional development

During the first three decades (1949 – 1980) after the establishment of People's Republic of China, central government is committed to achieving a balanced distribution of resource and production incomes (Wang & Hu, 1999). However, the Maoist redistributive policies were reversed to Deng's uneven regional development strategies from the 1980s (C. C. Fan, 1997). The concept of 'growth poles' was translated into the Chinese 'ladder-step theory' and underpinned China's regional development strategies. During the late 1980's and early 1990's, the central government implemented a series of policy interventions aiming at promoting growth and development at regions that already had comparative advantages, and hoping those regions will generate propulsive effects for other lagging regions (Wei, 2000). Pragmatism and the emphasis on efficiency foster the national policy initiative of dividing the nation into 'three economic belts' with assigned specific roles, and regional endowment is one major factor for this division (Beijing Review, 1986; C. C. Fan, 1997). The eastern coastal belt is designated as export-

oriented industrial activities and international trade, and has received substantial preferential policies.

Together with restrictions and obstacles to factor and resource mobility, these region-biased policies contributed significantly to the spatially differential growth rates and patterns between regions (D. T. Yang, 2002). Therefore, these region-biased policies aggravated the urban-rural and inland-coastal inequalities (Kanbur & Zhang, 1999; Tsui, 1993; D. T. Yang, 2002). Several studies and researches have found that the rural-urban gap is a more important contribution to overall regional inequality than inland-coastal inequality (Atinc & World Bank, 1997; Kanbur & Zhang, 1999; Tsui, 1993). However, Kanbur and Zhang's work further argues that the inland-coastal component has been growing at a faster speed from a previously low level.

The imbalance between the major metropolitan areas and the secondary areas is imperative: on the one hand, giant mega-cities are saturated with labor and resources, while on the other hand the peripheral areas are suffering from lack of necessary resources. With the widening development gap between regions and within regions, the uneven development approach has been questioned and challenged increasingly during the past decade (C. C. Fan, 1997). Although interregional growth is always unbalanced in geographic terms (Hansen, 1965), the differences in economic structure and growth may grow into interregional antagonism and conflicts between regions or within regions (Markusen, 1987, p. 225). Further expansions of regional differences may cause "serious social and political problems, generate nationalist conflicts and negatively influence China's economic and social stability" (Xue, 1997).

2.4.2. The need for polycentric development pattern

In China, the strategy of spatial containment and planned dispersal, also known as 'concentrated deconcentration' was proposed to counter the diseconomies of mega-cities. The ultimate objective is a more balanced urban system. Reconciling competitiveness and equity has already been central to China's planning policies and practices. In China, policy makers are becoming more concerned with equity and a more balanced distribution of people and activities in the territory. China's Ninth Five Year Plan (1996-2000) acknowledged the enlarged regional inequalities as an inevitable stage for a big country like China, and addressed a series of policy interventions to alleviate regional polarizations (**Li**, 1996). The Eleventh Five-Year Plan (2005-2010) sets a "harmonious socialist society" as one of its major goal, and focuses on addressing inequality by fostering the "coordinated development" in which disadvantaged groups and regions also shares the benefits of economic growth (C. C. Fan, 2006).

After more than two decades of competition for resources and preferential policies, Chinese cities finally reached the agreement of shared growth and development in megaregions (J. Yang, 2009). However, the competition between cities and regions does not vanish. Wei (Wei, 2000) conceptualizes China's economic transition as a triple process of decentralization, marketization and globalization. Decentralization has offered local governments more autonomy, authority and responsibilities (He, Wei, & Xie, 2008). With China's transition toward a 'socialist market economy', the focus of competition shifted from fighting for investments and favorable policies from central state to attracting investments from multiple sources. In order to attract investment, local

authorities build new transport infrastructure and upgrade existing ones. Without strategic coordination at the mega-regional level, there exist the risks of duplication and redundancy. Therefore a mega-regional approach is much needed to ensure that the limited resources are utilized most efficiently.

2.5. The variance and change of regional spatial patterns

This part examines the literature and research in regional economic development relevant to the variance and evolution of regional spatial patterns. It will substantiate the first main hypothesis: the spatial demographic patterns of China's megaregions vary significantly in polycentricity, and the evolution of megaregions' polycentricity is not a unidirectional progress.

Why variance?

Regions' growth trajectories depend upon 1) its locational constraints, 2) its internal immobile resources, and 3) its capacity to attract mobile resources from elsewhere and to retain its internally generated mobile resources (Richardson, 1973). The emergence and growth of mega-regions are the results of the interplay of a complex set of factors and mechanisms. Location, natural advantages, institutional frameworks have all played key roles in this process.

The research teams lead by Hall and Pain (Hall & Pain, 2006b) analyze and compare the polycentric patterns and functioning of eight megaregions in the EU. Their study employs the concept of both geographical or morphological polycentricity and functional

polycentricity. The morphological polycentricity is measured by: 1) rank-size analysis of constituent urban regions, 2) degree of self-containment and 3) commuter flows. The functional polycentricity is defined as information exchanges, and is analyzed through the organizational structures of multi-locational firms, patterns of business travel, telephone calls and emails between cities. Their research concludes that the eight megaregions reveal differences in their polycentric patterns by different measures. Considering the vast area of China, these mega-regions differ significantly in these factors - some are naturally fixed, while others change over time and are influenced by the cultural and social contexts.

In modern economies, labor, capital, institutions and other human factors are far more important than natural conditions for regional economic development. Institutions structuring the political and economic frameworks confer comparative advantages on mega-regions. There have been attempts to describe underlying driving forces for the evolution and growth of regions, and the politics of local economic development. Current regional growth theories offer different models and interpret this from different perspectives.

Through examination of the growth trajectory of Chicago and the Great West, Cronon (1991) refers to booster theories and argues that “a city’s history must also be the history of its human countryside, and of the natural world within which city and country are both located”. According to booster theories, natural advantages, including resources, transportation routes and global climatic forces, make future metropolis a natural

outgrowth of its region, and human labor was less important than nature in spurring a city's growth.

Some theories about local governments' economic development activities focus on the structure of local governments, the mobility of capital across fixed geographic boundaries, the competition among cities for mobile capital and fiscal imperatives. Peterson and Swanstrom (Peterson, 1981; Swanstrom, 1988) argue that given the mobility of capital across local governmental boundaries, cities have a unitary interest in the well-being of their economy and in attracting economic activity. The notion of a "unitary interest" in growth in urban politics has been described as essentially an abstraction of U.S. urban political economy (Orum, 1991; Pierre, 1999).

Molotch (1976) claims that the very essence of a locality is its operation as a growth machine, and any locality is conceived as the expression of the interests of certain land-based elite who will benefit through the increasing intensification of the land use of the area. Because of the finiteness of the degree of growth, localities are in competition with each other to gain the preconditions of growth. He argues that U.S. cities were created and sustained largely through this process, which continues to be the significant dynamic of contemporary local political economy and is crucial to the allocation of public resources and the ordering of local issue agendas. Government, private corporations, property owners and investors, employers, builders and bankers together made up the "urban growth machine". Therefore, not only government decisions, but also decision made by private corporations and others who have their fortune tied to the growth of the metropolis, have major impact on local growth chances.

Endogenous sources of growth based on technological process, learning by doing, and dynamic externalities (E. L. Glaeser, Kallal, Scheinkman, & Shleifer, 1992) have led to the argument that, institutional frameworks within which firms and cities operation may condition what they can achieve, and regions may derive comparative advantages from their institutional frameworks.

Jacobs (1969) proposed the concept of reciprocating system to explain how cities start growing. She argues that a city's exports and some of the goods and services produced locally to serve the export work act together to create an economic reciprocating system, and this reciprocating system functions in cities not only when they are first forming and growing, but as long as their economies grow and diversify, no matter how complex the cities themselves become. She emphasized the multiplier effect of import replacing, which is achieved through knowledge transferring from outside the region. Consistent with Jacobs' theories, a more recent study (E. L. Glaeser et al., 1992) found that local competition and urban variety, but not regional specialization, encourage economic growth in industries, and suggests that important knowledge spillovers might occur between rather than within industries.

Lucas (1988) considered technological change as an alternative engine of growth and introduced human capital into the production model. He argued that human capital accumulation generates external effects, which enhance the productivity of both physical capital and labor capital. It is observed that schooling, on-the-job-training, and learning-by-doing are important methods in the formation and accumulation of human capital.

Similar arguments about the importance of human capital in economic growth have been made by Romer. Romer (1990) developed a model which is driven by technological change that arises from intentional investment decisions made by profit-maximizing agent. His findings imply that an economy with a larger total stock of human capital will experience faster growth. He also suggests that different levels of human capital may help explain growth rate differentials between developed countries and underdeveloped countries. It is argued that basic research may have a stronger impact on economy growth than applied research (Osano, 1989). The endogenous growth model also recognizes the role of government decisions and activities in regional economic development. Government could permanently raise the long-run growth rate, if government can influence the parameters of the growth model, e.g. savings behaviors, research and development, and population growth (Nijkamp & Poot, 1998).

Glaeser (2007) examines the factors behind the growth of American metropolitan regions into mega-regions. He comes to the conclusion that it is the initially less dense areas that have experienced the fastest growth and speculates that this reflects the general move to car-based, space intensive living. He also finds that warmer places have grown more quickly than colder regions, which suggest that climate seems to play a part in the development of the fastest growing regions. However, he finds no evidence that initial income impacts population growth in the mega-regions; instead he finds that population growth is an effect of successful housing supply.

Why not unidirectional?

As listed above, regional growth is results of a complex set of factors besides transport infrastructure: location, natural environment, living cost, quality of life, institutional frameworks, employment opportunities, and most importantly considering China's unique context – region-biased development policies; and the mechanisms of the interplay between these factors is even more complex. While the locational and natural factors are generally fixed, the remaining factors can be changed. In the modern global economy, human-made comparative advantages are far more important than natural advantages for regional economic development. One important aspect of this modern reality is that pattern of human-made comparative advantages can change and do change over time (Blinder, 2006).

Within China, jobs have moved to the South, while the traditional industrial regions in the North become the "rust belt" of China, and are burdened with a disproportionate share of outdated state-owned enterprises. In addition, offshoring of jobs in both manufacturing and service industries from developed countries to developing countries has become a widespread trend during the past several years, and South China has become main offshore outsourcing destinations from developed countries. Under these fast changing global, national and regional trends, the evolution of the spatial patterns of China's megaregions will evidently be a complex non-unidirectional process.

2.6. The development trajectory of core and peripheral areas

This section investigates interregional disparities between regions in the contemporary economic and institutional framework. This section substantiate the second main hypothesis: the growth impact of transport infrastructure differs between the core and peripheral areas, and it also depends on the stages of development.

Interregional growth is always unbalanced in geographic terms, and there always has been regional inequality (Hansen, 1965). The economic developments within mega-regions and between mega-regions are not even. The differences in economic structure and growth have caused economic competition and sometimes antagonism within mega-regions or between mega-regions. These interregional antagonism and conflicts can occur, even if the economic structure of the regions involved have been growing increasingly similar over time (Markusen, 1987, p. 225).

The question whether regional economies are converging or diverging has long attracted the attention of economists and decision makers. Perloff's (1960) empirical studies for regions of the United States over a century found evidence of income convergence, although there were exceptions. Allowing for factor mobility, the Borts and Stein (1964) model analyzed the consequences of three disturbances to the growth differentials among U.S. regions, including change of the rate of growth of the labor supply, rise of export prices and narrowing of the inter-sectoral wage differential.

By analyzing the "spread effects" and "backwash effects" of centers of economic expansion to other regions, Myrdal (1957) argues that market forces tend to increase

inequalities between regions through the process of cumulative causation, and the interplay of these two kinds of effects may lead to a stagnating balance, not a stable equilibrium. By analyzing the movement of ‘efficient wages’, Kaldor (1970) argues that relatively fast growing areas tend to acquire a cumulative competitive advantage at the expense of the relatively slow growing areas.

Perroux (1950) defined the term ‘growth pole’ as the economic centers where the centrifugal forces that emanate from and the centripetal forces that are attracted to. It is within those poles that economic growth and changes are initiated. Hirschman (1958) argues that the growth of developed regions may have both favorable trickling-down effects and adverse polarization impacts on the lagging areas. . He believes that in the long run, the trickling down effects will gain the upper hand over the polarization effects. Friedmann (1972) proposed the core-periphery model, based on the analysis of the linkages between innovation and authority. Like the accumulative causation theory, Friedmann suggests that the dominance of core regions over the periphery tends to be self-reinforcing, especially at the early stages of development. However, the rising opposition of the periphery may lead to a sharing of authority or the replacement of the core areas, and this lead to the transformation of the structure of the spatial system.

The general principles of agglomeration identified by economists since Marshall are still applicable in contemporary urban environments. Chinese cities, of course, are subject to the same forces and dynamics of agglomeration. In addition, major cities in the megaregion should play a pivot role and serve as growth poles in the region. In order to

reach the critical mass to function as growth poles, the metropolitan cores need to grow at a faster speed compared with peripheral regions.

As suggested by Williamson (Williamson, 1965), rising regional income disparities and increasing regional dualism is typical of early development stages, while regional convergence and a disappearance of severe regional dualism problems is typical of the more mature stages of national growth and development. Therefore, the agglomeration of resources in the core metropolitan areas seems natural and necessary to achieve an extensive economic growth at the national scale for China. In the past two or three decades, the capacity expansion and upgrades of transport infrastructure in China unblock the existing bottlenecks and establish the previously missing links. This served more as facilitating the gathering of resources from surrounding areas to support the economic activities of the core metropolitan areas, rather than as facilitating the dispersion of opportunities to the peripheral regions.

Wallis (1994a, 1994b) has described regionalism in the United States as occurring in a succession of waves, which he links to three stages: the mono-centered industrial metropolis, the polycentric metropolis, in which municipalities compete for economic advantage within their nations while duplicating each other's efforts to provide needed services, and the third stage in which inter-municipal competition within single regions has given way to inter-regional competition for service-dominated enterprises on a global scale. The emergence of mega-regions and the trend of globalization imply that the U.S. regionalism is leaving the second stage and entering the third stage.

In the last two decades of the 20th century, China's regional development was essentially the evolution of the first stage, mainly about forming the giant metropolis that dominates regional and even national economies. Only after some core metropolitan areas reached their critical mass and the saturation stage at the beginning of the 21st century, this accumulative process of concentration of resource in the major metropolitan areas was questioned. Afterward, China's regionalism is leaving the first stage and entering the second stage. Because of the finiteness of the degree of growth, localities are in competition with each other to gain the preconditions of growth.

Regional convergence and a disappearance of severe regional dualism problems is typical of the more mature stages of growth and development (Williamson, 1965). In the long run, the trickling down effects will gain the upper hand over the polarization effects (Hirschman, 1958). In addition, as suggested in Friedmann's (1972) core-periphery model, the rising opposition of the periphery may lead to a sharing of authority or the replacement of the core areas, and this lead to the transformation of the structure of the spatial system.

The globalization of financial and production networks increases the mobility of labor and capital dramatically, and this brings both opportunities and challenges to regional economic development to both the developed and developing countries. Krugman (1995) has examined the impacts of globalization on national economies through a model in which regional differentiation is driven by the interaction between scale economies and transport costs. He proposed a U-shaped pattern of global economic change, of divergence followed by convergence corresponding to different stages in the process of

globalization. The world economy must achieve a certain critical level of integration before the forces that cause differentiation into core and periphery can take hold. When that differentiation occurs, the rise in core income is partly at peripheral expense. As integration proceeds further, however, the advantages of the core are eroded, and the resulting rise in peripheral income may be partly at the core's expense.

China has extended and upgraded its highway systems and built an extensive network of high-speed railways, and spatial transaction costs have fallen dramatically in recent decades. With the central state's emphasis on achieving shared economic development, these transport network investments are believed to bring the beneficial effects to a larger scale. However the risks of 'pump effects' and 'tunnel effects' still need to be acknowledged. Economic activities still tend to agglomerate together in geographic space to secure the external economies developed in the interaction networks and share various benefits of agglomeration (Scott, 1996). Transportation infrastructure doesn't guarantee economic development and regional integration. Researches have confirm that infrastructure investments are not self-sufficient, higher marginal returns happen when it is combined with other services, e.g. physical and human capital (David Canning & Bennathan, 2000; Fernald, 1999).

2.7. Development impacts of transport infrastructure

This part surveys the relevant research and literature relevant to the development impacts of transport infrastructure to substantiate the second and third hypothesis.

2.7.1. Development impacts

Aschauer is the pioneer to study the relationship between transport infrastructure and regional development. His influential works (Aschauer, 1989a, 1989b) of the US economy claim that infrastructure endowment have significant impacts for economic productivity and growth. He defines transport infrastructure along with other civil infrastructure as 'core infrastructure', and found that that core infrastructure has more explanatory power for productivity. Aschauer (Aschauer, 1989a) indicates that public investment is likely to raise private investment, and thus public investment policy can influence, to a dramatic extent, the trajectory of capital accumulation, economy, and regional growth, which is a 'nonneutral' process. Since Aschauer, numerous follow-up studies have been undertaken to explore the role of infrastructure as a stimulus to economic growth.

Vickerman (Vickerman, 1995, p. 227) summarized that the effects of transport infrastructure for regional development can be classified into non-spatial impacts and spatial impacts: non spatial impacts are the effects of transport infrastructure on the economic productivity and the aggregate level of economic activity; spatial impacts of transport infrastructure can lead to differential performance is different locations, and this will happen at various scales. The following part will provide the relevant literature in these two classifications.

Impacts for economic performance

Rephann and Isserman (Rephann & Isserman, 1994) examines the effectiveness of interstate highways for counties which obtained link or are in close proximity to these

newly linked counties during the period 1963-1975. Their study shows that the newly constructed interstate highway infrastructure favors regions that are in close proximity to large cities or regions that are already urbanized to some extent.

Using Census of Manufactures for 48 states for the years 1972, 1977, 1982 and 1987, Holzt-Eakin and Lovely's study (Holtz-Eakin & Lovely, 1996) confirmed that infrastructure increases the number of individual establishments, and thus raising manufacturing output. The increased number of establishments led to external returns, and thus the rise of manufacturing productivity.

Considering productivity as the impact of transport infrastructure for regional development in all Spanish regions, Moreno and López-Bazo (Moreno & López-Bazo, 2007) revealed that the positive impact of improvements in infrastructure is closely related to the existing endowment, which follows the rules of decreasing returns to the accumulation of capital of this kind. Like several other studies, this study also found negative territorial spillover across regions in transport capital, possibly caused by competition for factors of production across regions. The time span of study is from 1965 to 1997. During the early 1960's, infrastructure endowment and economic activity in the Spanish regions are far below the European level, after it only started to catch up after Spain joined the EU in 1986. Therefore, this study shed lights on the effects of infrastructure on the takeoff of less-developed economies when they first started to open and modernize.

Using Granger-causality test in a Vector Auto Regression framework, Sturm et al. (Sturm, Jacobs, & Groote, 1999) studied the output effects of transport infrastructure

investment in the Netherlands during the 1853-1913 period, and found a positive impact of transport infrastructure investment on Dutch GDP.

Using data for California counties from 1969 through 1988, Boarnet (Boarnet, 1998) argues the existence of negative output spillovers from transport infrastructure. His study shows that changes in county output are positively associated with changes in street-and-highway capital in the same county, but are negatively associated with changes in street-and-highway capital in other counties.

Impacts for population and employment

Using county level data of population (1970 and 1980) and employment (1969 and 1979), Mills and Carlino (E.S. Mills & Carlino, 1989) argue that a high-density interstate network attracts both population and employment growth.

Meijers' study (Meijers, Hoekstra, Leijten, Louw, & Spaans, 2012) looks at local growth rates for employment and population from a new transport infrastructure project- the Westerschelde tunnel in Netherlands. They emphasize the importance of geographical, sectoral, and demographic details of the social and economic impacts of transport infrastructure. The study area is at a more detailed scale composed of villages, towns and medium-sized cities. Their results show that accessibility increases in center lead to employment decreases, while accessibility gains in periphery lead to slightly positive rates. Population growth does not exhibit any significant impacts from accessibility: center experiences population growth at the expense of the periphery regardless of local change in accessibility.

Rietveld (Rietveld, 1994) conducted a survey of studies on the spatial economic impacts of transport infrastructure supply. Based on the literature survey, at the interregional level, infrastructure supply has a considerable impact on the productivity of other production factors, but the relocation impacts of transport infrastructure on economic activity are usually limited.

Dodgson (Dodgson, 1974) examines the employment impacts of the M62 Motorway in Britain on 30 local areas from 1961-1966, and found positive relationship between employment growth and accessibility. Botham (Botham, 1980) extends the analysis to a national level, and analyses the employment impacts of the road building program of Britain during the 1961-1966 period. Similar results were found by Botham, and he argues that road programs has had a centralizing effect on the distribution of employment.

Duranton and Turner (Duranton & Turner, 2012) estimate the effects of interstate highways on the growth of U.S. cities between 1983 and 2003. Their study finds that a 10% increase in a city's initial stock of highways causes about a 1.5% increase in its employment over this 20 year period. Their study also suggests that an additional kilometre of highway allocated to a city at random is associated with a larger increase in employment or population than is a road assigned to a city by the prevailing political process.

2.7.2. Differentiated beneficial returns from transport investment

Button (Button, 1998, p. 152) summarized a series of studies about the estimated output elasticities of public infrastructure, indicating that results vary between different studies

which employ different methods. Lakshmanan (Lakshmanan, 2011, p. 5) summarized a series of recent studies of the output and cost elasticities of highway capital in different countries. He concludes that despite the modest positive economic contributions of infrastructure in a majority of the recent studies, there exist sharply different results: 1) for the same country, at different periods of time; 2) for different countries at comparable stages of development; and 3) for countries at different stages of development. And these different or even conflicting results are not caused methodological deficiencies.

Andersson et al (Andersson, Anderstig, & Hårsman, 1990) distinguished between several aspects of transport infrastructure: main road, railroad, and airport capacity, travel time to major metropolitan area and interregional travel time in the Swedish regions. Their study found that for 1970 the impacts of railroads on regional production were stronger than main road, while the situation reversed in 1980, and the effects of main roads became stronger.

Cantos et al (Cantos, Gumbau-Albert, & Maudos, 2005) analyzes the impacts of different modes of transport on the economic growth of the Spanish regions during the 1965-1995 period. Their results confirm the existence of substantial spillover effects associated with transport infrastructures, and the effects of road infrastructure for economic growth measured by production seem to be more predominant and significant.

Using county-level total earning as measurement of economic growth during the 1969-1993 period, Chandra & Thompson (Chandra & Thompson, 2000) found that highways have differential impacts varying by industries and by spatial locations. Certain industries grow due to reduced transportation costs, while other shrink as economic activity

relocates. In addition, the level of economic activity in counties that highway pass through are raised at the expenses of adjacent counties.

Canning and Bennathan's (D. Canning & Bennathan, 2007; David Canning & Bennathan, 2000) study estimates return of productivity to paved roads for a panel of 41 countries with different income levels. They found that in all developed and high-income countries, and all in poorer developing countries, the rate is less than one, while in most middle-income countries, the ratio far exceeds one. They conclude that countries with middle-income levels have higher marginal rates of return, while most developed countries have lower rates of return.

The differentiated rate of returns to transport infrastructure is caused by several reasons. First, decreasing rate of return to transport infrastructure has been acknowledged in previous studies (D. Canning & Bennathan, 2007; Moreno & López-Bazo, 2007). In developed countries/regions, rate of returns to capital/infrastructure diminishes slowly because they increase their human capital accordingly to keep up the marginal rate of return (D. Canning & Bennathan, 2007, p. 50). In addition, the overall impact of transport infrastructure improvement on a region will depend on, amongst other things, its sectorial structure (Button, 1998). Different industry sectors use transport infrastructure with differing intensities, so the production costs and the subsequent employment shifts will change at different rates. Button argues that (Button, 1998) employment will grow for those sectors which have high price elasticities and higher intensities of infrastructure use, while other sectors will experience decline of employment.

2.7.3. China Studies

Démurger (Démurger, 2001) used a sample of 24 Chinese provinces during the 1985-1998 period to estimate the links between infrastructure investment and economic growth measured by GDP per capita. The results indicate that transport facilities are a key differentiating factor in explaining the regional economic growth gap.

Using provincial-level data for 1982–1999 in China, Fan and Chan-Kang's research (S. Fan & Chan-Kang, 2008) finds that the benefit/cost ratios of low-grade (mostly rural) roads for national GDP (8.66) are about four times of the benefit/cost ratios for high-grade roads (2.34). Their research points out the tradeoff between economic growth and poverty reduction. Their research differentiated the effects yielded by road investment in different parts of China: the highest economic returns by national GDP growth in the eastern and central regions of China; while poverty reduction effects are greatest in western China (especially the southwest region). One limitation to most studies of China's transport infrastructure is using provincial-level data. Growth results from infrastructure investment are aggregated into a larger geographic unit, which does not distinguish the different effects for the sub-units. In addition, road length is often used as the simple proxy for transport infrastructure level, and the quality differences is not often included.

Yu et al.'s (Yu, de Jong, Storm, & Mi, 2013) study of China's transportation stock for GDP found that the positive spillovers exist at the national level, but it also exhibits striking variances across regions and across different periods. Their study analyzes the spillover effects of transport infrastructure of the four regions during three time periods:

1978-1990, 1991-2000 and 2000-2009. The eastern region had positive spillover during all three periods, while the other three regions have seen significant negative spillover in at least one of the three periods. The negative spillovers indicate that economic gains from transport infrastructure may be at the expense of other regions.

Yu et al. (Yu, De Jong, Storm, & Mi, 2012) look at the differentiated effects of transport infrastructure for economic growth in China, and found that the highest output elasticity in the central regions, which indicates that transport investment, will yield the highest economic returns in the central regions. Similar results have been found by Zhang (Xueliang Zhang, 2007).

Zhou and Ma (Zhou & Ma, 2000) argue that transportation improvement is one of the reasons which contributed to the shift of population from urban centers to suburban areas. Their study of suburbanization of Beijing, Shanghai, Shenyang and Dalian shows that population in urban cores decreased during the period 1982-1990.

2.8. Limitations of existing literature

Limitation of literature in regional spatial patterns

Existing research and literature focused on the three giant coastal mega-regions in China, and the remaining inland mega-regions have not been given much attention. Although these inland mega-regions are of smaller scale, it does not mean that they are less important. Therefore, this study will provide a comprehensive analysis of the ten megaregions in China.

A significant research challenge has been to construct the appropriate measure for spatial polycentricity. The scale on which the concept of polycentricity is applied ranges from individual cities to regions, even beyond national borders. Davoudi (2003) observes that as the scale increases, the concept of polycentricity becomes gradually less analytical. Groth and Smidt-Jensen (2007) acknowledged the ideological characteristic of the concept and the contradictory qualities due to its sensitivity to scaling and political commitments.

There is no clear and established definition and measure of polycentricity at the mega-regional level. Most of the previous research and literature about polycentricity is limited to the conceptual or qualitative level. Therefore it is necessary to clarify the meaning and measurement of centers and "polycentricity" in the mega-regional context.

Yang et al. (J. Yang, French, Holt, & Zhang, 2012) developed urban form metrics using spatial statistical approaches to measure the polycentric structure of the 50 largest U.S. metropolitan areas. Since this research focuses on the spatial patterns of megaregions, a promising approach to dealing with the above methodological challenge is to develop a measure of polycentricity at the mega-regional level.

Limitation of literature in the impacts of transport infrastructure

First, there is no general agreement on the relevant framework or methodology to evaluate the development implications for major transport infrastructure projects (Linneker & Spence, 1996). Although most studies have found positive effects of transport infrastructure, the existing literature is still inconclusive. The effects of

infrastructure differ depending on the type of infrastructure and the nature of spatial units under consideration. As Morrison (Morrison, 1993) puts it, 'A clear consensus about the impacts of infrastructure investment has as yet been elusive, at least partly because different methodologies generate varying results and implications'

As mentioned before, the effects of transport infrastructure for regional development can be classified into non-spatial impacts and spatial impacts (Vickerman, 1995, p. 227). One major limitation of the exiting literature is that studies on transportation infrastructure tend to focus on its effects on economic indicators, such as the productivity, income and aggregate output. The spatial implications for household/population are often neglected. However, considering the extremely high population density in some of the megacities, the issue of spatial pattern of population settlement is imperative. The over-congested living environment in many of the major cities of China raised the critical question of the implications of transport infrastructure improvements for the spatial pattern of population.

A large share of the existing studies of the spatial implications of transport infrastructure are about the impacts of specific infrastructure projects at a smaller scale. Comprehensive studies of the spatial implications of transport infrastructure at the national level have been limited. In addition, most of the existing researches are at a more aggregate level: e.g. state/provincial level or even country level. The effects of spatial differentiation at the sub-regional level will be hidden or lost in an analysis at aggregated spatial scales. Therefore analyses of transport infrastructure at more geographically detailed spatial

scales are much needed. Only geographically detailed studies are able to reveal the spatial differentiation patterns.

One major puzzle about the impacts of transport infrastructure is the differentiation between the two major modes of transportation: roadway and railway. Railway and roadway transport infrastructure have beneficial implications for regional development in the long term, however the beneficial effects of road and rail differ. It also depends on other factors, e.g. location, settlement density, existing economic development level. The coastal-inland/east-west difference is also a major factor. However, the existing literature offers extremely limited empirical findings that differentiate between roadway and railway.

Finally, one basic weakness in the majority of existing studies is the failure to establish the causal relationship (Rietveld, 1994). This is partly due to the availability of data, and establishing a causal relationship requires a longer span of time. The lack of controlling for unobservable territorial and time effects casts doubt on the effectiveness of transport infrastructure investment in some of the existing research studies (Moreno & López-Bazo, 2007, p. 67). In addition, available dataset on infrastructure and especially the infrastructure quality is limited, especially at the lower spatial levels, and lack of coherence of data at the national level hinders the research.

CHAPTER 3. METHODOLOGY

3.1. Study area and background

3.1.1. China's megaregions

One of the major challenges for megaregion research is the definition of megaregional boundary, which is more conceptualized than being operationalized, and does not necessarily follow political boundaries. There has not been consistent boundary definition or criteria to define boundaries. The boundary definition of some megaregions are more stable, and clearer than the others, while others are more vague and unclear. In this research, the boundary of China's China's ten megaregions follows the most commonly accepted definition given by the National Development and Reform Commission of China (Xiao & Yuan, 2007), which is listed below:

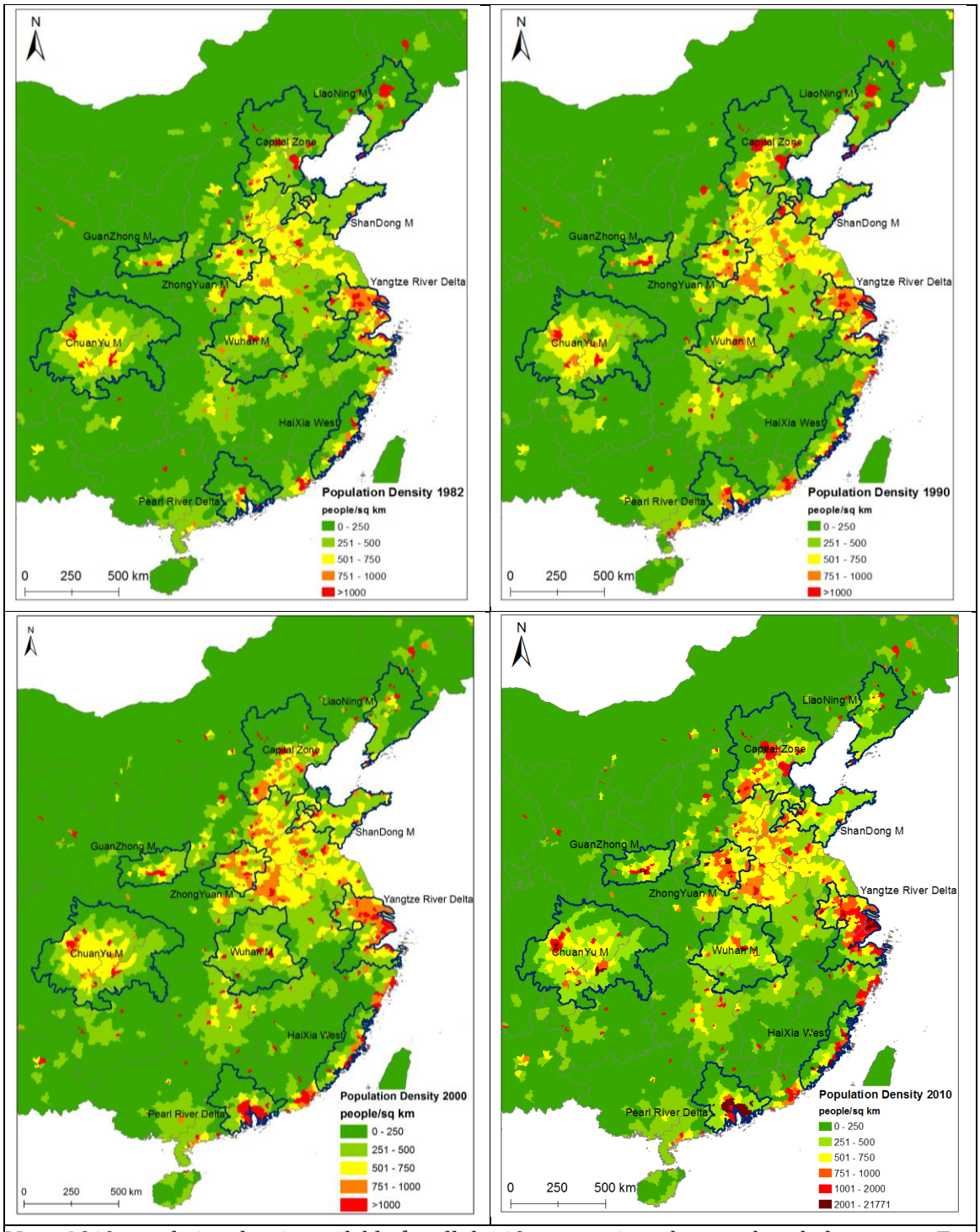
- Capital Economic Zone: the core centers of Capital Economic Zone are Beijing and Tianjin, surrounded by 8 cities from Hebei Pronvince, including Shijiazhuang, Baoding, Qinhuangdao, Langfang, Cangzhou, Chengde, Zhangjiakou, and Tangshan.
- ChuanYu MegaRegion: the core center of ChuanYu Megaregion are Chongqing and Chengdu, surrounded by 13 cities from Sichuan Princince, including Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guan'an, Ya'an, and Ziyang.
- GuanZhong MegaRegion: the core center of GuanZhong MegaRegion is Xi'an, surrounded by Xianyang, Baoji, Tongchuan, and Weinan.

- HaiXia West MegaRegion: the core centers of Haixia West MegaRegion are Fuzhou and Xiamen, surrounded by Zhangzhou, Quanzhou, Putian and Ningde.
- LiaoNing MegaRegion: the core centers of Liaoning MegaRegion are Shenyang and Dalian, surrounded by Anshan, Fushun, Benxi, Dandong, Liaoyang, Yingkou, Panjin, and Tieling.
- Pearl River Delta: the core centers of Pearl River Delta are Guangzhou, Shenzhen, and Hong Kong, surrounded by Zhuhai, Huizhou, Dongguan, Qingyuan, Zhaoqing, Foshan, Zhongshan, Jiangmen and Macao.
- ShanDong MegaRegion: includes Jinan, Qingdao, Yantai, Zibo, Weifang, Weihai, Dongying, and Rizhao.
- Wuhan MegaRegion: the core center of Wuhan MegaRegion is Wuhan, surrounded by 14 cities from 3 pronvinces, including Huangshi, Ezhou, Huanggang, Xiantao, Qianjiang, Xiaogan, Xianning, Tianmen, Suizhou, Jingmen, Jingzhou, Xinyang , Jiujiang and Yueyang.
- Yangtze River Delta: the core center is Shanghai, surrounded by 6 cities from Zhejiang Pronvince and 8 cities from Jiangsu Province. These cities include Hangzhou, Jiaxing, Huzhou, Shaoxing, Ningbo, Zhoushan, Nanjing, Yangzhou, Changzhou, Taizhou, Zhenjiang, Wuxi, Nantong, and Suzhou.
- ZhongYuan MegaRegion: the core centers are Zhengzhou and Luoyang, surrounded by 7 cities from Henan Province, including Kaifeng, Xinxiang, Jiaozuo, Xuchang, Pingdingshan, Luohe and Jiyuan.

Among the above 10 megaregions, six of them are in the coastal areas and four of them are in middle or western part of China. This research uses the prefecture level city boundary as the basis when creating megaregion boundaries, which are shown as blue boundary in Figure 3-1. These ten megaregions exhibit various characteristics. Using the 2000 Census data, the following map shows the county-level population density information. Table 3-1 lists land area, population, population density for the ten megaregions from 1982 to 2010. In 2010 among the ten megaregions, Yangtze River Delta has the highest population density (1064 people/sq km), while LiaoNing has the lowest population density, which is 353 people/sq km. Megaregions are where higher densities locate (Figure 3-1), and over the past three decades densities have increased steadily for all the ten megaregions (Figure 3-2).

Table 3-1 Population of megaregions (1982-2010)

	Area (1,000 sq. km)	**Population (million)**				**Population density (people/sq. km)**			
		1982	1990	2000	2010	1982	1990	2000	2010
Capital Economic Zone	181	55	63	71	80	304	348	391	443
ChuanYu MegaRegion	267	94	101	106	101	351	377	395	375
GuanZhong MegaRegion	56	17	19	22	23	302	347	390	420
HaiXia West MegaRegion	52	18	21	24	29	341	396	465	543
LiaoNing MegaRegion	90	25	28	30	32	280	312	331	353
Pearl River Delta	73	26	31	50	65	354	427	691	879
ShanDong MegaRegion	70	33	36	39	41	469	515	558	580
Wuhan MegaRegion	147	48	54	59	56	325	366	397	379
Yangtze River Delta	93	62	66	77	101	670	707	825	1064
ZhongYuan MegaRegion	58	29	34	38	41	499	577	642	698



Note: 2010 population data is available for all the 10 megaregions, but not the whole country. For countries where data is not available, population densities are substituted by 2000 data.

Figure 3-1 Population density of megaregion (1982-2010)

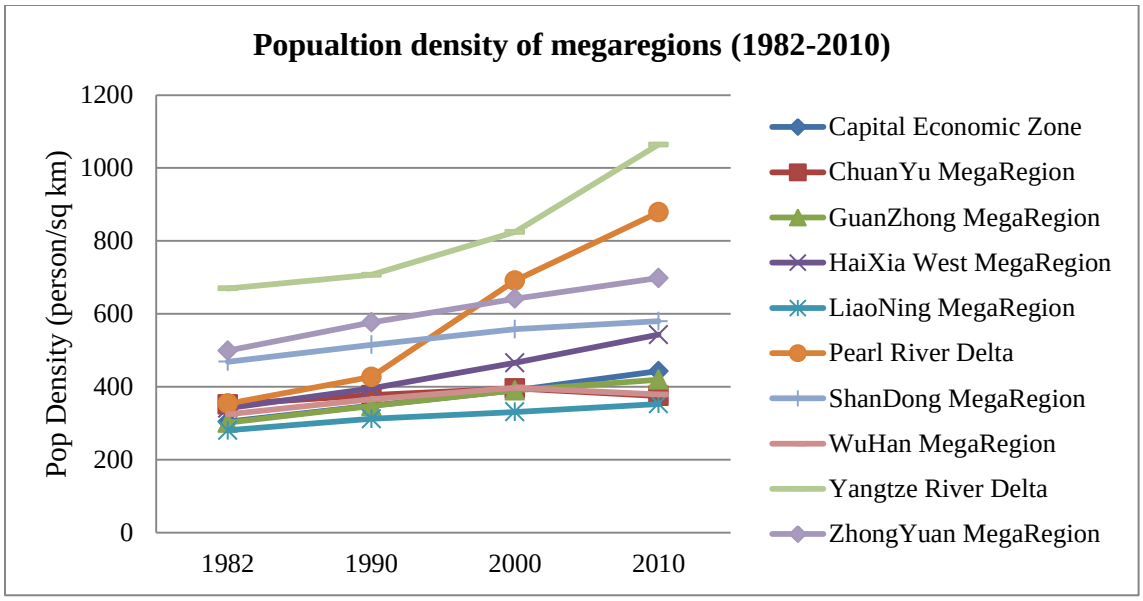


Figure 3-2 Change of population density of megaregions (1982-2010)

3.1.2. China's Transport Development

Transport infrastructure planning is one of the key tasks for megaregional planning, and it is also one crucial factor to achieve shared development and regional coherence. In China, high-speed railways, highway, airports and other traditional transportation modes have been used to establish greater links between cities within each mega-region and between mega-regions. The completion of mega-region transport systems strengthens connections between all the cities of the region and cut journey times between cities. With cities reached from each other within short travel time, regional barriers in terms of travel cost are reduced significantly during the past several decades.

Railway, particularly high-speed railway is being promoted as a new highly efficient alternative to road transportation, especially passenger transport. For example, with the

operation of the first high-speed rail link from Beijing to Tianjin with a speed of 300 km/h, journey times between these two major cities have been reduced substantially to half an hour. This new transport axe is expected to strengthen the economic powerhouse effects of Beijing and Tianjin, and to stimulate the economic competitiveness of the whole mega-region. For Wuhan Megaregion, the high-speed railway network connecting Wuhan and other major cities in China, e.g. Guangzhou, Shanghai, Beijing is being constructed. The completion of high-speed rail network removes the bottlenecks in existing transport infrastructure. With the completion of this high-speed rail network, the journey times between Wuhan and these major cities is cut significantly to around 4 hours, and this enables people and goods to circulate quickly and easily between mega-regions. The Yangtze River Delta transportation scheme involves the construction of new high-speed railways, highways and bridges, upgrading of conventional rail lines and motorways, and upgrading of maritime infrastructures (Figure 3-3). These major improvements will facilitate linkages between major cities, make both passenger and freight journeys quicker and more efficient and strengthen YRD's position as China's economic gateway.

Since the operation of the first high-speed rail line, Beijing-Tianjin line, China's expanding high-speed railway network had a total length of 8358 km of lines in operation by the end of 2010 (Tantao News, 2011). The major corridors connect the north to the south in the coastal part and the central part of China.

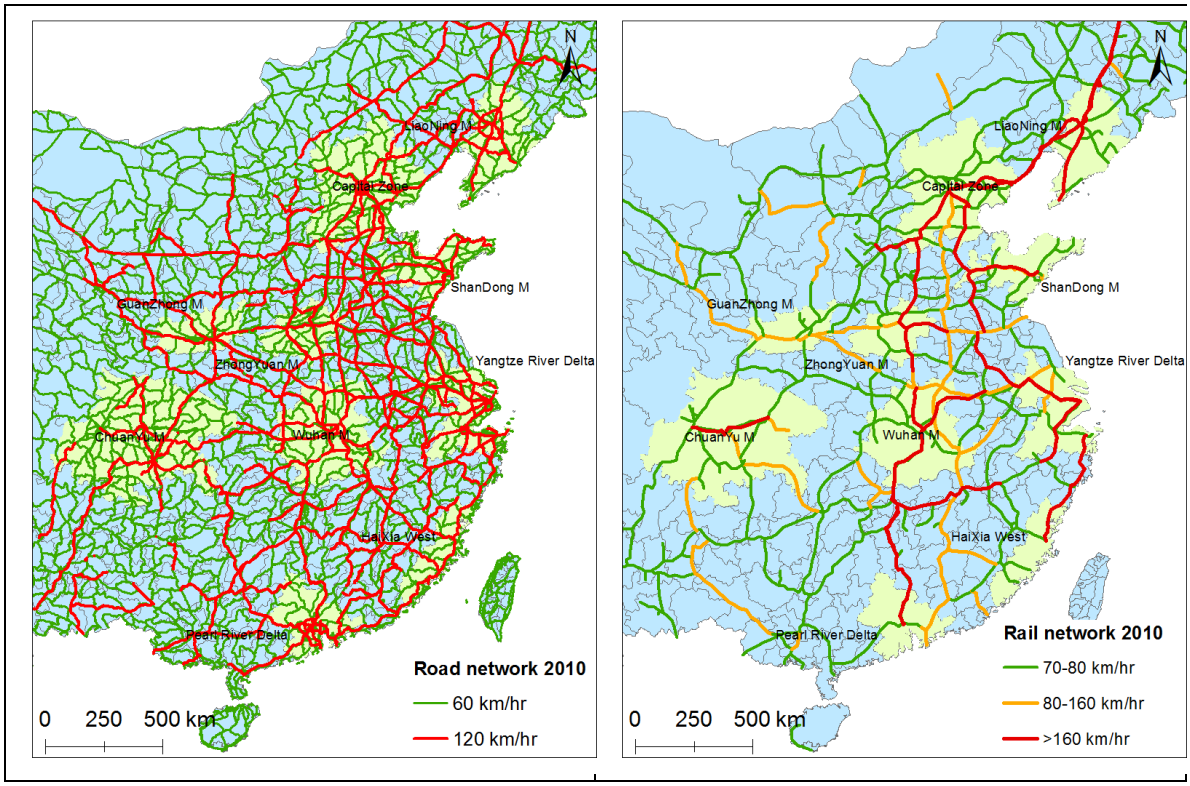


Figure 3-3 Road and railway network of China (2010)

3.2. Conceptual framework and research hypotheses

3.2.1. Conceptual framework

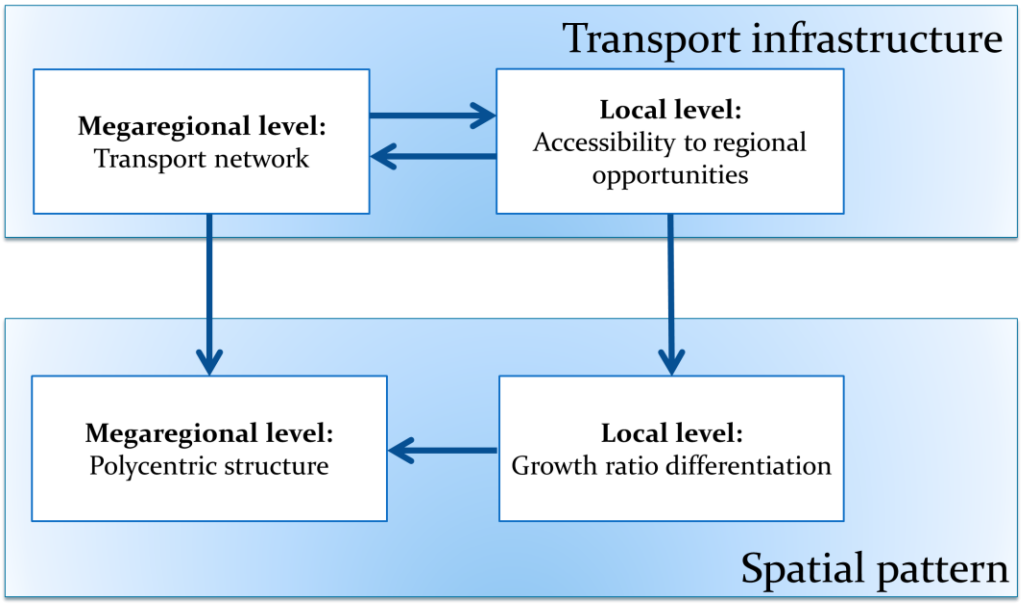


Figure 3-4 Conceptual framework

This study aims to explore the relationship between transport infrastructure and regional spatial patterns for the ten megaregions of China. This relationship functions at two levels: the megaregional level and the local level (Figure 3-4). At the megaregional level, the structure of transport network impacts the spatial pattern of megaregions. Ideally, a highly connected transport network will contribute to a more polycentric spatial pattern.

At the local level, each local unit is connected to the surrounding destinations through the transport network. The regional network decides local unit's accessibility to regional activities through its effective stock of transport infrastructure (Cantos et al., 2005; Holtz-

Eakin & Lovely, 1996; Moreno & López-Bazo, 2007). A local unit's endowment of transport infrastructure is different from the physical stock of transport capital: access to roads and highways in the region contributes to the effective stock of public sector input, causing it to exceed to the stock physically within the state's border.

In the modern economy, cities are connected with each other. Local unit's accessibility to regional economic activities has significant impacts on the local growth trajectory. In this research, growth level will be measured by population density and population growth rate. The differentiation of local growth rates leads to the division into core and peripheral areas, and thus decides the formation and evolution of regional spatial patterns.

As shown in Figure 3-4, the connection between transport network and regional spatial patterns is analyzed at two levels – the megaregional level and the local level. These two levels are intertwined together.

3.2.2. Research hypothesis

Hypothesis 1: The spatial demographic patterns of China's megaregions vary significantly in polycentricity. The evolution of megaregions' polycentricity is not a unidirectional progress.

Literature review Section 2.5 examines the literature and research in regional economic development relevant to the variance and evolution of regional spatial patterns, which substantiates the first main hypothesis. The methodology part will define the measurement of polycentricity of megaregions. This research will calculate

the polycentricity index for ten megaregions in 1982, 1990, 2000 and 2010 to conduct cross-sectional and longitudinal analysis of the spatial pattern of megaregions.

Hypothesis 2: The recent large-scale transport network development impacts growth in both the core and the peripheral areas. Their differentiated effects vary between core and peripheral areas. At the early stages of development, the resulting growth in core areas is higher than the peripheral areas.

Literature review section 2.6 and section 2.7 survey the relevant research and literature to substantiate the second main hypothesis: the growth impact of transport infrastructure differs between the core and peripheral areas, and it also depends on the stages of development. In this research the classification of core and peripheral areas will adopt two criterions: by density and by locations. Local units with population density higher than twice of megaregional average population density are defined as megaregional centers. The first classification method adopts this definition, and a dummy variable (center) will be generated.

Coastal areas are more developed than inland areas, and therefore the second classification method defines coastal area as core areas and inland areas as peripheral areas. It should be noted that this division between coastal and inland is more about the features of the megaregions, less about the location, because not all cities within a coastal megaregion locate along the coast. A location dummy of coastal area will also be included when the megaregional dummies are not included to analyze if there is any consistent trend between coastal and inland areas.

Hypothesis 3: The growth impacts of railway and road vary. The impacts of rail infrastructure for urban growth are bigger than road infrastructure.

Literature review section 2.7 provides an extensive review of the studies about the development impacts of transport infrastructure. Different modes of transport infrastructure have different effects. In China, road and railway are the two major modes of transportation at the regional level. Despite the recent rising trend of car ownership in the past decade, railway is still the dominant mode for regional transportation. Therefore it is expected that the regional growth impacts of railway will be greater.

3.3. Data sources

This research uses the following datasets:

First, digital geographic data of transport infrastructure, and boundaries of provinces, prefecture-level cities and counties are used to define the basic geographic framework for this study.

Second, China's population county-level census data (1982, 1990, 2000 and 2010) are used in conjunction with the GIS layers to analyze spatial patterns of megaregions. Comparisons between these time points will show the dynamics of the spatial patterns of population and economic activities. The 1982 and 1990 Censuses used household registration population, while 2000 and 2010 Censuses used long-term resident

population. It should be noted that there are differences between these two census methods.

Third, attribute information of transport infrastructure are geo-coded based on documents from multiple sources, e.g. historic maps, documents and online-sources. Roads are classified into regular regional road and highway; railways are classified into regular rail and high-speed rail. Other relevant attribute information includes construction time, upgrade/expansion time, roadway design speed and railway service speed. It should be noted that design speed adopted in this research may not reflect the actual travel speed, especially in some highly congested areas. However actual travel speed is not available at the nationwide level, and thus this research uses design speed to calculate travel time.

3.4. Methodology

This research will go through a sequence of 6 tasks, which will answer the three research questions accordingly (Table 3-2). The methodology is conceptualized in Figure 3-5 and explained below.

Table 3-2 Research question and research tasks

Research Questions	Research tasks
How polycentric are China's megaregions? Have the megaregions become more polycentric or not?	Task 2 & Task 3
Does transport investment significantly impact megaregional spatial pattern? If so, in what direction and magnitude.	Task 4 & Task 5
What adjustment in transportation planning and policies can help fostering a more polycentric megaregional spatial pattern?	Task 6

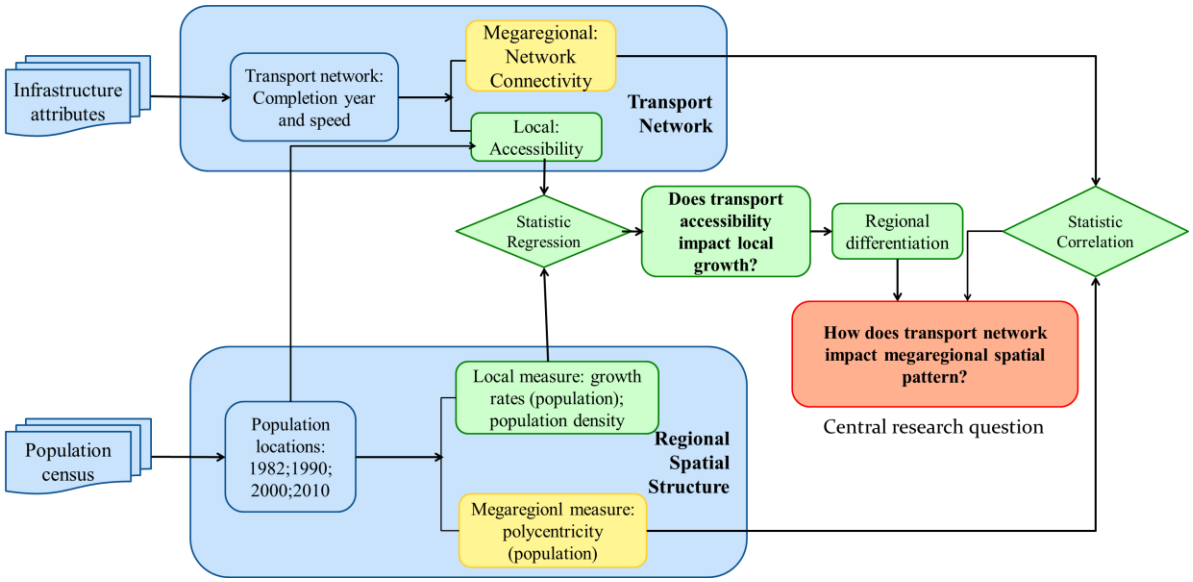


Figure 3-5 Data and Methods

3.4.1. Task 1: Data Collection and Integration

The GIS layers containing administrative boundaries and transport infrastructure are collected. The census data for 1982, 1990, 2000 and 2010 is collected and input into GIS database. The transport infrastructure attribute data is collected and geo-coded. All data is assembled into a geodatabase. The processed dataset is the foundation for assessing the spatial patterns of China's megaregions and evaluating the implications of transport investment for urban spatial patterns.

3.4.2. Task 2: Measuring polycentric development

Mega-regional boundaries do not necessarily follow political boundaries, which is a challenge for megaregion research. In this research, the boundaries of China's ten

megaregions follow the most commonly accepted definition. This research will use the prefecture level city boundary as the basis when creating megaregion boundaries.

The ten megaregions exhibit striking diversities, and therefore analysis of mega-regional polycentric structure should take into account the different density characteristics of individual megaregions. In particular, the definition of economic centers should be based on the specific situations of different megaregions. The ratios of counties' population densities to the megaregional mean population density are calculated. A ratio higher than 1 means one county's population density is higher than the average population density of its megaregion. The further away one county's population density is from its megaregional mean population density in the positive direction, it is more likely that a county may function as a regional center. All component counties in each megaregion will be classified into three classes:

- **1st class** is the **main center** of megaregions. Counties with ratios higher than 2 are defined as megaregional centers.
- **2nd class** is the **middle-class**. Counties with ratios between 1 and 2 are classified into middle-class.
- **3rd class** is the **low density** class. Counties with ratios lower than 0 are classified into this category.

The GIS spatial statistics tool – Directional Distribution: Standard Deviational Ellipse, is utilized to measure the spatial distribution of different density classes for individual

megaregions. Two Standard Deviational Ellipses will be calculated separately: for the main center class and the entire megaregion.

The polycentricity index of mageregioal center is defined as:

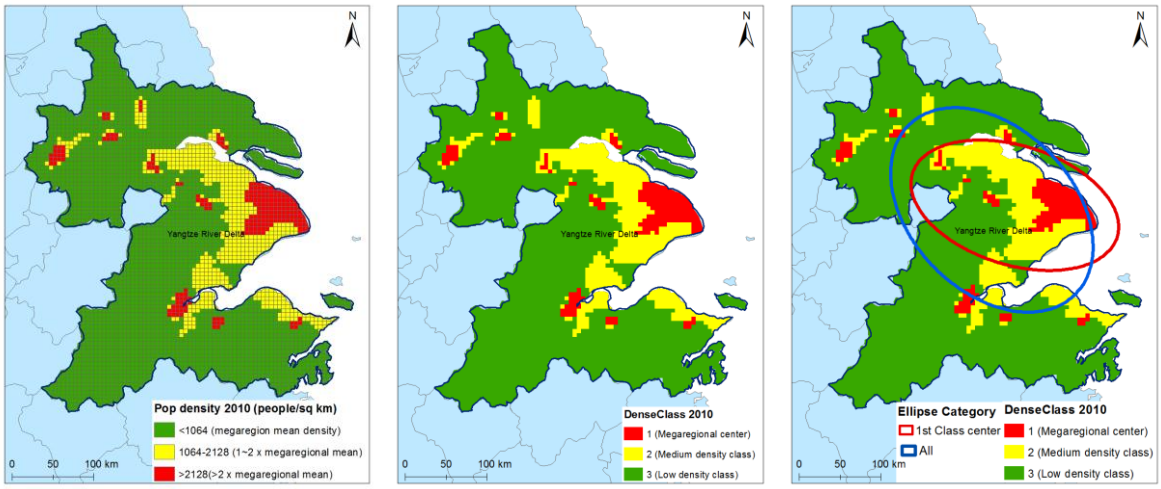
$$\textbf{Major center polycentricity} = \frac{\text{Ellipse area of 1st center class}}{\text{Ellipse area of all classes}}$$

A key proposition here is that: a megaregion of higher polycentricity should have multiple megaregion centers and those centers should be spatially distanced from each other to maximize access to economic centers throughout the region. Mapping this proposition to the statistic measure, the standard deviational ellipses of the high density classes (major centers) in a more polycentric region should resemble the standard deviational ellipse for the whole megaregion more closely. The ratio of the area of the ellipse of the 1st class to the area of the ellipse of the entire megaregion, this ratio should typically ranges from 0 to 1, as high density centers tend to be more geographically concentrated than low density areas. In addition, a ratio closer to one indicates higher polycentricity.

In the pilot study, counties were used as the component analysis units. Problems were encountered due to inaccurate geographic boundary in the GIS dataset. Some of the smallest counties (urban districts) have extremely high population densities. Because of their small areas, boundary inaccuracy would cause relative large error for some of the smallest counties. In order to control this problem, a 5km*5km grid layer is overlaid and intersected with the county level polygon layer, and then the county level population was

reassigned to grids, with each grid inheriting the population density characteristics from its intersecting county. The smallest counties (urban districts) were either completely contained in or split by the grids. The extreme population density values are then flattened.

Using Yangtze River Delta as an example, Figure 3-6 summarizes how the polycentricity index is calculated.



Step 1: Calculate population density for each grid. In 2010, the average population density for Yangtze River Delta is 1064.	Step 2: Grids are classified into three classes.	Step 3: Calculate Standard Ellipse for 1st density class, and the whole megaregion. Calculate polycentricity index.

Figure 3-6 Steps for calculation of polycentricy

3.4.3. Task 3: Assessing changes in mega-regional spatial structure

Multiple year data are synthesized to analyze the spatial dynamics. The population indicators of 1982, 1990, 2000 and 2010 can illustrate how mega-regional spatial patterns have changed.

The population growth rate for each local unit during the periods of 1982- 1990, 1990-2000 and 2000-2010 will also be calculated. In addition, two GIS spatial analysis techniques will be utilized to describe and identify the spatial pattern of megargions and the linkages between local growth and regional spatial patterns. The first one is Hot Spot Analysis tool, which identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). It will be used to identify the locations and patterns of spatial clustering of high growth rate areas. The second one is the Spatial autocorrelation (Moran's) Index for the growth rates will be calculated using GIS. A positive Moran's I index value indicates tendency toward clustering while a negative Moran's I index value indicates tendency toward dispersion. This index can thus assess the association between the growth of local unitswith its neighboring counties' growth.

3.4.4. Task 4: Measuring mega-regional transport network development

This research will develop two levels of measures for transport network, one for the mega-regional level, and the other for the local units composing megaregions:

Megaegional Level:

The most popular network measurement - **network density** measures the territorial occupation of a transport network in terms of length of links (L) per unit of land area (S). The higher the network density is, the more a transport network is developed.

However this measure is mainly concerned about the geographical or spatial characteristics of transport network. It does not take into consideration the population served by the infrastructure network, and thus ignores the demand side of transport

infrastructure. For this reason, **per capita road length** will also be calculated. This is a very meaningful measurement of megaregional transport network, because it is argued that the supply of transport infrastructure is more responsive at the regional and national level, much less so at the urban level (Ingram & Liu, 1997).

Yet, infrastructure quality is not reflected by these two measurements. Simply taking physical numbers may disguise some important measurement. Infrastructure upgrades and speed increases, which are the major transport infrastructure improvements in the last two decades, are not reflected in these measures.

Therefore the two measures - network density and per capita road length, will be modified to include a weight factor. The ratio of the design speed to a standard speed will be assigned to road segments as the weights. Thus the infrastructure upgrades and speed improvements will be reflected in these two measures. In 1982, the average road and rail speed is 40 km/hour, and thus 40 km/hour will be used as the standard speed to calculate the weight for each link.

Local Level:

This research adopts two types of approaches for measuring transportation network at the local level: 1) the simple travel cost measurement, which measures the connectivity of local component units; and 2) the gravity model-based approach, which measures the potential regional accessibility of economic activities.

Connectivity:

The most basic measures of travel cost include travel distance or travel time. Because the recent transportation projects are mainly speed-increasing, therefore this research measures travel time as the travel cost, the average travel time from one local unit to all the other destinations in the same megaregion. A modified approach of the simple travel cost measure is proposed: population weighted travel cost. The travel cost for each origin-destination pair will be given a weight, which is the population of the destination. The assumption is that a travel connection to a destination of more activities (symbolized by a large population) is more important than the connection to a destination of smaller population. Therefore the connectivity of one local unit is defined as:

$$\text{Connectivity of i} = \frac{\sum_j (time_{ij} * population_j)}{\sum_j Population_j}$$

Where:

i is the local unit of origin

j is all the other destinations within the same megaregion

$Time_{ij}$ is the network travel time between i and j

$Population_j$ is the population of the destination, which functions as the weight for the travel cost.

Accessibility**:**

The local level measurement of accessibility calculates component counties' accessibility to mega-regional activities. As summarized by Handy (1993), accessibility has two components: a transportation element or resistance factor and an activity element or motivation factor. The transportation element reflects the ease of travel between locations

as determined by the character and quality of service provided by the transportation system and as measured by travel distance, time or cost. The spatial element reflects the distribution of activities, characterized by both the amount and location of different types of activities (S. L. Handy & Niemeier, 1997; S. Handy, 1993). This research adopts the gravity model approach to calculate transport accessibility. It can be interpreted as the volume of activity opportunities that can be accessed from a given point after the travel impediment has been account for (Gutiérrez, 2001). Accessibility measurement combines the travel impediment to, and the attractiveness of the destinations in a single indicator (Geertman & Ritsema Van Eck, 1995).

In this research, the travel impediment will be measured by travel time, and the attractiveness will be measured by total population of the destinations.

$$A_i = \sum_j \frac{M_j}{T_{ij}^{\lambda}}$$

Where:

A_i is the potential accessibility of place i,

M_j is the 'mass', in this research populations of destination j

T_{ij} is the travel time or cost between origin i and destination j and

λ is the distance decay or friction parameter

The choice of the magnitude of distance decay parameter is one limitation of this method. Using the 1970 airline passenger interaction data between the 100 largest Standard

Metropolitan Statistical Areas (SMSAs) in the US, Fotheringham (Fotheringham, 1981) empirically estimated the 100 origin-specific distance-decay parameters which showed a marked spatial pattern. The parameter estimations range from 0.1 to 2.6, with the majority between 0 and 1. Parameter instability is inherent because of the complexity of spatial interaction behaviors, and thus model variability is viewed as an inevitable result (Eldridge & Jones, 1991; Jones, 1992). Theoretically the distance decay effects on spatial interaction behaviors are context-specific, varying by geographic settings and also by different human activities (Xingyou Zhang, Lu, & Holt, 2011). A greater parameter means that travel cost have stronger effects, and in this research spatial interaction activities are more sensitive to travel time. In this research λ will be set to 1.

Two travel modes will be considered in this research: by railway and by roadway. For the mode of railway, the network consists of railway and road: railway is the primary mode of transport, while roads serve as connectors from local units to railway stations. For the mode of roadway, the network consists of highways and regular roads. Utilizing GIS network analysis tools OD matrix, for each local unit, the travel time to all the other counties in the same megaregion will be calculated on the basis of the length of trip segments and the estimated design/service speed. Local units' accessibility by road and by rail will then be calculated.

3.4.5. Task 5: Assessing the impacts of mega-regional transport infrastructure for megaregion spatial pattern

This research will explore the relationship between transport network and spatial pattern at two levels: the megaregional level and the local level.

Megaregional level

At the mega-regional level, the model will analyze the relationship between megaregional transport network and the polycentricity index. The hypothetical relationship is that highly connected transport network will lead to a more balanced regional spatial pattern.

1) The first model uses transport network density in the base year as the main explanatory variables, and is specified as:

$$Polycentricity_j = polycentricity_{j-1} + coastal + megapopdes_j + roaddes_{j-1} + raildes_{j-1} + \varepsilon$$

Where:
j is the ending time period, and j-1 is the previous time period.
Coastal is a dummy variable (=1 when megaregion is classified as a coastal megaregion)
Megapopdes is the average population density for the megaregion at time period j.
$roaddes_{j-1}$ is the megaregional road network density at the previous time period.
$raildes_{j-1}$ is the megaregional rail network density at the previous time period

2) The second model uses transport length per capita in the base year as the main explanatory variables, and is specified as:

$$Polycentricity_j = polycentricity_{j-1} + coastal + megapopdes_j + roadcap_{j-1} + railcap_{j-1} + \varepsilon$$

Where:
$roadcap_{j-1}$ is the megaregional road network endowment per capita at the previous time period.
$railcap_{j-1}$ is the megaregional rail network endowment per capita at the previous time period.

3) The third model uses the size of the standard ellipse of transport network in the base year as the main explanatory variables, and is specified as:

$$Polycentricity_j = polycentricity_{j-1} + coastal + megapopdes_j + road\_ellip_{j-1} + rail\_ellip_{j-1} + \varepsilon$$

Where:

$road\_ellip_{j-1}$ is the area of the Standard Deviational Ellipse of megaregional road network at the previous time period.

$rail\_ellip_{j-1}$ is the area of the Standard Deviational Ellipse of the megaregional rail network at the previous time period.

Similar models using other alternative measures of polycentricity will also be run to test the relationship between transport network and spatial pattern at the megaregional level.

Local level

Investments in highway/high-speed railway change the demographic spatial pattern of megaregions as a whole through its differentiated beneficial effects on its component units. At the sub-mega-regional level, the transport accessibility and population growth for the component counties will be modeled to analyze the impacts of transport infrastructure for local growth. The resulting data will be used for statistical analysis. Regression models will be developed to find out how transport investment as illustrated by accessibility measures can help explain changing spatial pattern for megaregions, through its effects on megaregion's component units' growth rates. The dependent variable will be population density and growth rates of population. The emergence and growth of mega-regions are the results of the interplay of a complex set of factors and mechanisms. The potential explanatory variables include: economic structure, urban characteristics, transport accessibility, demographic structure, labor market conditions, and natural climate (Blumenthal, Wolman, & Hill, 2009). The literature review has identified a series of factors besides transport infrastructure that can influence regional

growth: location, natural environment, living cost, quality of life, institutional frameworks, employment opportunities, and most importantly considering China's unique context – region-biased development policies. This research is inevitably limited by the variables available at the county level, especially with the constraint that the most recent 2010 census is not publicly available yet. To make allowance for the effects of omitted variables, dummy variables for the 10 megaregions are included to account for locational, climate and other regional factors.

This research will apply four statistical models: panel regression, OLS, multi-level model, and spatial regression. This research will mainly use the results from panel regression and OLS to interpret the effects of transportation network for megaregional spatial patterns, while the results from Multi-Level Model and spatial regression will complement the results of panel regression and OLS models. The main statistic package used in this research is STATA, and GeoDa is used to conduct spatial regression.

1) **Ordinary least square:** OLS is the most fundamental statistic approach
2) **Panel regression**: the dataset is a short panel dataset. The ten megaregions have around 1,000 local units (after adjusting for administrative boundary discrepancy between different time periods), and 4 time periods (1982, 1990, 2000 and 2010). Therefore, panel regression is an appropriate approach.
3) **Multi-level regression:** the dataset has a hierarchical structure of local counties nested in 10 megaregions. Local units are grouped into 10 megaregions. Mixed models consist of fixed effects and random effects.

4) **Spatial regression:** Diagnostics of OLS regression using GeoDa reveals that the error terms across different spatial units are correlated, and thus with spatial error in OLS regression, the assumption of uncorrelated error terms is violated. As a result, the estimates are inefficient. Spatially correlated error term (LAMDA) is added as an additional indicator to control omitted (spatially correlated) covariates that if left unattended would affect inference (GIS at Brown, 2013).

Regression model:

- Dependent variable: population density; population growth rates 1982-1990, 1990-2000, 2000-2010
- Potential Explanatory variable: transportation accessibility/connectivity, natural climate, and regional location

As previously discussed, it is important to rule out spurious causation between county growth and transport infrastructure: if new transport infrastructure improvements are being constructed in areas of high growth (transport improvement is endogenous), then the causal effects would be overstated. Reverse causality occurs when economic growth happens first, and then it entails increased supply of transport infrastructure. Ignoring reverse causality may lead to overestimation of the beneficial effects of transport infrastructure, and therefore the coefficients for the accessibility variables may be overestimated (S. Fan & Chan-Kang, 2008). This research tries to explore causal relationship between transportation infrastructure and urban growth, and rule out the effects of reverse causality.

Establishing a causal relationship has always been a challenging but fundamental question for social sciences. For social sciences which are based on nonexperimental data, the most dominant approach has been some version of the cross-lagged panel model (Allison, 2012). The method of Granger causality has been used in some previous researches of the impacts of transport infrastructure. The general idea can be summarized as: A variable X Granger-causes Y if Y can be better predicted using the histories of both X and Y than it can using the history of Y alone (Sewell, 2001). If Y is regressed on lagged values of Y and X and the coefficients of the lag of x are statistically significant, then it implies that X Granger-cause Y, or X can be used to predict Y.

Using the method of Granger Causality, Eberts and Fogarty (Eberts & Fogarty, 1987; Munnell, 1990) found positive influences of public infrastructure investment for private investments. Using the approach of different lag intervals, Hartog et al. (Hartog, Heineken, Minne, Roemers, & Roodenburg, 1986; Rietveld, 1989) suggested a causal relationship between public and private investments, with an interval of 3 or 4 years, while the reverse relationship is not founded from statistical analysis. Applying the concept of Granger causality, this research uses lagged explanatory variables to analyze causal relationship.

One major limitation of this this research is the existence of endogeneity due to lack of controlling for unobservable territorial and time effects. The classic instrumental variable approach has been used in similar problems. But in this research it is not feasible due to lack of data as appropriate instruments.

3.4.6. Task 6: Exploring policies for mega-regional transportation planning

The above modeling results can probably substantiate the statement that increased regional connectivity will bring beneficial effects to local development, and the improved connectivity for the secondary cities and towns will move the spatial patterns of megaregions toward a more polycentric direction. However, it still remains unanswered that 'how to plan and implement properly'. Policy analysis will be conducted to assess the possible impacts of the existing and most recent changes in transportation policies and initiatives. Conceptual linkages between polices and transport network structure will be proposed. Necessary policy adjustments will be proposed for better economic, social, and environmental regional cohesion.

CHAPTER 4. ANALYSIS AND FINDINGS

The findings are organized by the research tasks, and will answer the main research questions accordingly.

4.1. Megaregional spatial patterns:

4.1.1. Polycentricity

Figure 4-1 shows the classification of component counties within megaregions and the Standard Deviational Ellipses generated. Figure 4-2 gives a simple summary of the number of megaregional centers for the ten megaregions during the 1982-2000 period. Because of administrative boundary changes and possible errors of GIS boundary data, this research uses a 5km*5km grid layer as the framework for spatial analysis. Therefore, a center is one unit of grid which is classified as megaregional center.

During the 1982-1992 period, all megaregions except Haixia West megaregion have experienced increases of total number of megaregional centers; during the 1990-2000 period, most megaregions have less megaregional centers, and only Pearl River Delta and Yangtze River Delta have more megaregional centers; during the 2000-2010 period, the majority of the ten megaregions (6 out of 10) experienced growth of the number of megaregional centers.

Despite the fluctuations, the majority of megaregions (7 out of 10) have experienced overall increases in the number of megaregional centers; the total number of megaregional centers have decreased in three megaregions: Haixia West Megaregion,

Liaoning Megaregion, and Zhongyuan Megaregion. Pearl River Delta had the greatest increases of number of megaregional centers during the past three decades: in 1982, 232 units are classified as megaregional centers, and in 2010, 505 units are classified as megaregional centers.

The trends of the number of megaregional centers are in general consistent with the trends of polycentricity indexes. The polycentricity scores are calculated and results are shown in table 4-1 and figure 4-3. The score calculation has the following characteristics: 1) centers are defined by the ratio between local unit's population density and megaregional average density in the same year, which helps control the variation of the megaregional average density; 2) scores are calculated as a ratio, which helps control the size of the megaregion. It is expected that the polycentricity scores should not be systematically correlated with the land and population size and the density of the megaregion. A correlation analysis confirms that.

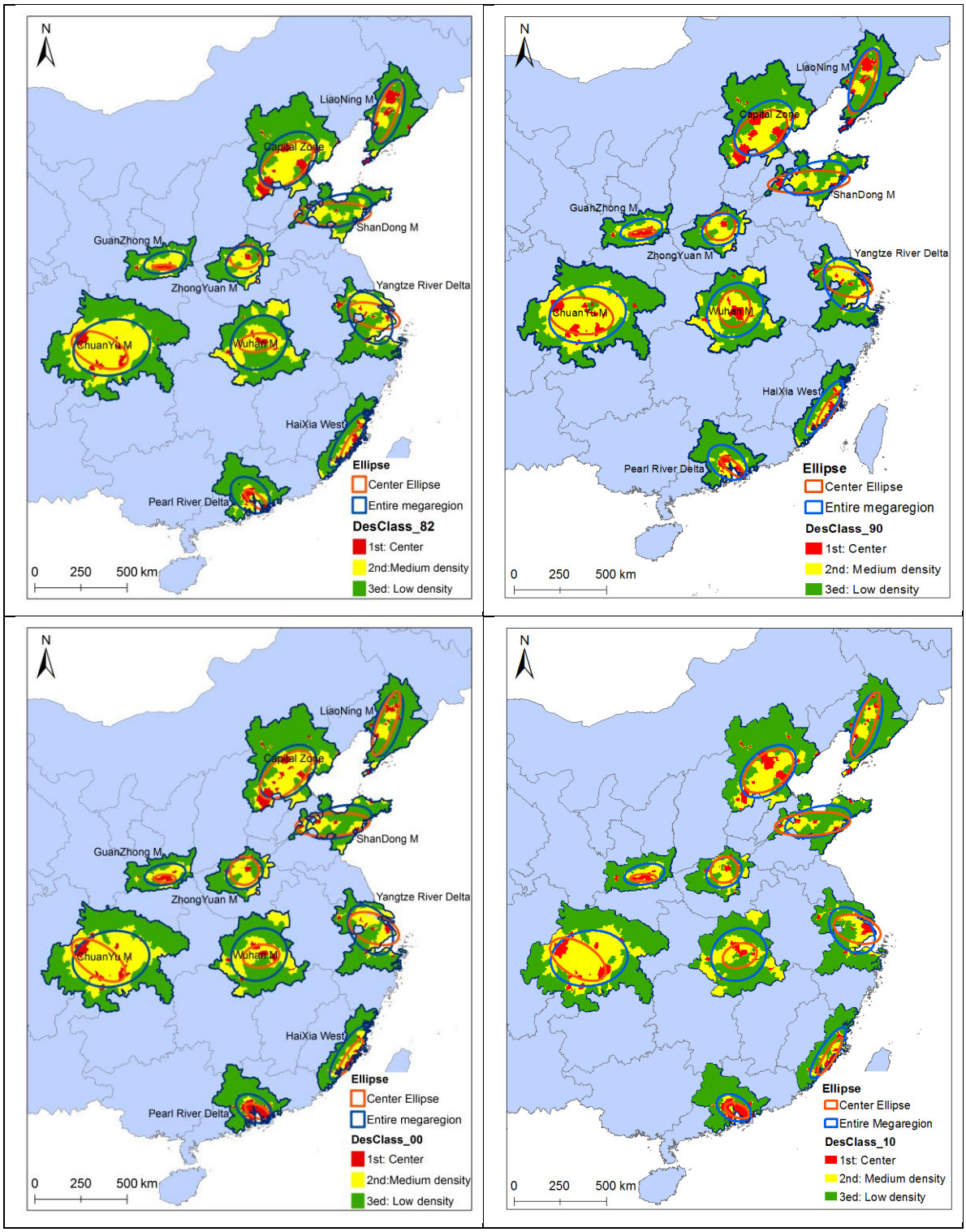


Figure 4-1. Density classes and ellipses for megaregions (1982-2010)

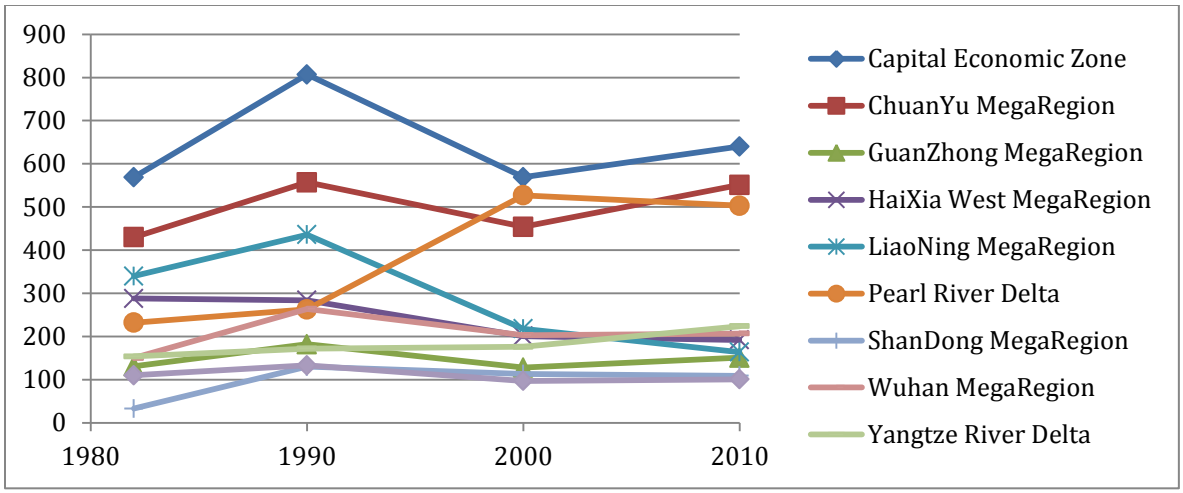


Figure 4-2 Number of centers in megaregion: 1982-2010

Table 4-1 Polycentricity score (1982-2010)

Mega-regions (ratio>2)	**1982**	**1990**	**2000**	**2010**
Coastal megaregions				
Capital Economic Zone	0.70	0.72	0.73	0.73
LiaoNing MegaRegion	0.71	0.77	0.68	0.71
ShanDong MegaRegion	0.86	0.85	0.82	0.87
Yangtze River Delta	0.57	0.66	0.72	0.66
HaiXia West MegaRegion	0.39	0.40	0.40	0.44
Pearl River Delta	0.25	0.26	0.34	0.39
Inland megaregions				
ChuanYu MegaRegion	0.44	0.54	0.44	0.48
GuanZhong MegaRegion	0.12	0.21	0.20	0.25
ZhongYuan MegaRegion	0.62	0.71	0.71	0.67
Wuhan MegaRegion	0.23	0.38	0.28	0.28

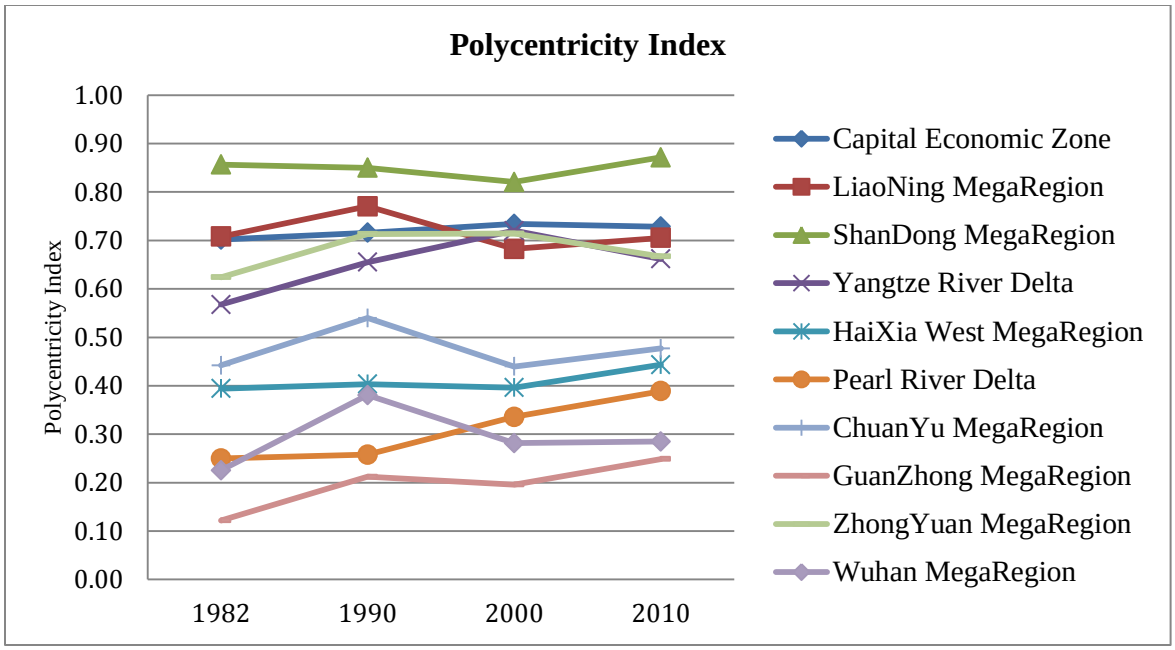


Figure 4-3 Polycentricity score (1982-2010)

During the 1982-1990 period, the polycentricity indexes for nine of the ten megaregions increased, Shandong megaregion is the only megaregion which show a slight decrease in polycentricity from 0.86 to 0.85 (table 4-1 and figure 4-3). The growth ratios differ by megaregions, but most of them are modest. This trend of increase flattens out during the 1990-2000 decade, with five megaregions showing increase or having the same level of their polycentricity indexes.

During the 2000-2010 period, the polycentricity indexes for two megaregions – Yangtze River Delta and Zhongyuan Megaregion dropped, while the other eight megaregions either show polycentricity increases or stay at the same level.

Despite the fluctuations of polycentricity index during the three time periods, all the ten megaregions have steadily become more polycentric during the whole study period from 1982 to 2010. It should be mention that all the ten megaregions have exhibit rather stable spatial patterns, and their polycentricity indexes have been rather stable. The biggest increase in polycentricity from 1982 to 2010 happens in Pearl River Delta, with an increase from 0.25 in 1982 to 0.39 in 2010, while Liaoning Megaregion is the only megaregion with the same polycentricity index in the beginning year and ending year of the study period.

A One-way ANOVA test of megaregional polycentricity by coastal generates $F(1, 39)=9.78$, $p=0.034$, and it reveals that the effect of coastal location is significant at the 0.05 level. The coastal group has an overall average (1982-2010) polycentricity of 0.61, and the inland group has an overall average (1982-2010) polycentricity of 0.41. Therefore, over the three-decade period 1982-2010, megaregions in the coastal area are more polycentric than the inland megaregions.

4.1.2. Alternative measures of polycentricity

As mentioned before, there is no established definition or measurement of polycentricity. Therefore this research also provides a series of alternative measures for interpreting the spatial patterns of megaregions. Four supplementary indexes focusing on megaregional centers are calculated to help illustrate the spatial pattern of megaregions, and the basic statistics for these four alternative polycentric statistics are presented in Appendix A.

- Index *Center per million population* (center_permill_pop) calculates the number of megaregional centers that per million people have, and it is a measure of number of centers standardized by megaregional population.
- Index *Center per km* (center_perkm) is a similar measurement, and it calculates the number of megaregional centers that per sq. km has, and it is a measure of number of centers standardized by megaregional area.

Not surprisingly, these two measures are strongly correlated (Pearson Correlation of 0.79) (table 4-2). The correlation between polycentricity index and these two alternative measures is not statistically significant. These two alternative measures are purely quantitative measures. Spatial locations and spatial relationships are not considered in these two measures. Nevertheless, they all provide meaningful input into our understanding of the spatial patterns of megaregions.

The general overall trend of number of megaregional centers per million population (Figure 4-4) from 1982 to 2010 is decreasing for the majority of the ten megaregions. This indicates that megaregions had fewer megaregions if standardized by population. The trend for number of megaregional centers standardized by area (Figure 4-5) is the same with the trend of total number of megaregionl centers. During the period 1982 to 2010, the majority of the ten megaregions (7 out of 10) have experienced overall increases in number of megaregional center. In 2010, capital economic zone and Pearl River Delta has the highest number of megaregional centers standardized by population; Pearl River Delta has the highest density of megaregional centers standardized by area, far exceeding other megaregions.

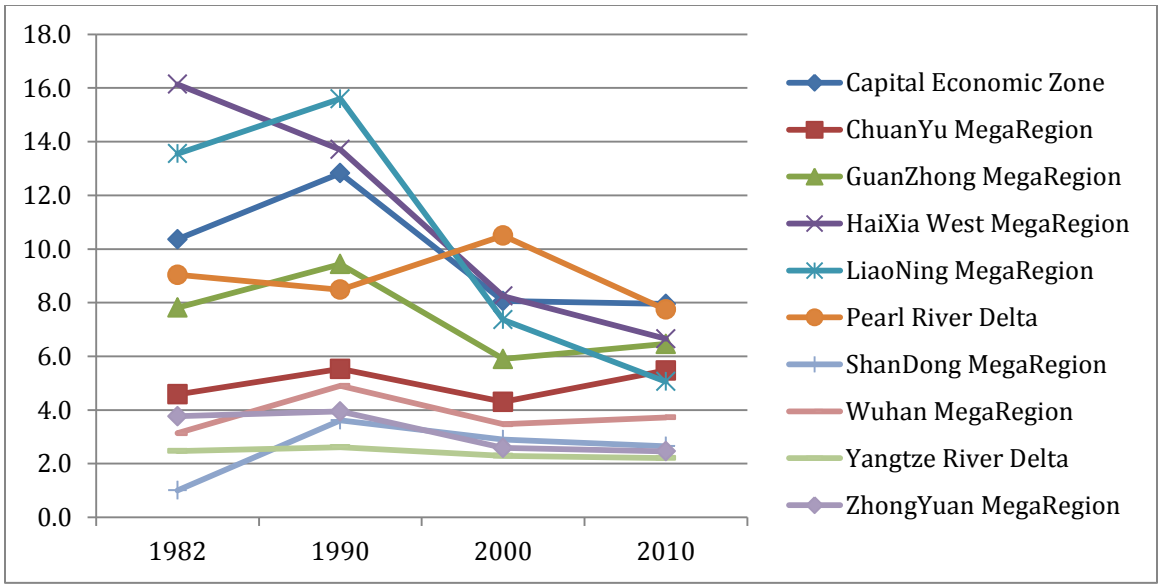


Figure 4-4 Number of centers per million population

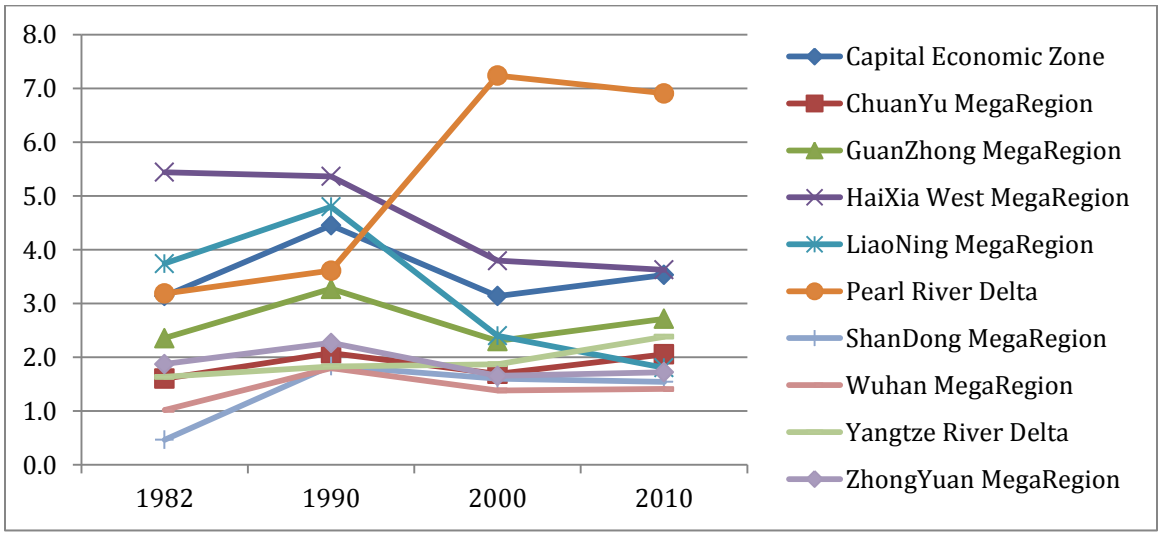


Figure 4-5 Number of centers per thousand sq km

- Index *population served per center* (pop_per_center) is basically the inverse of center_permill_pop. It calculates how many people are allocated to a

megaregional center, and it provides information about the average level of service or development of the centers for the whole megaregion.

The majority of the ten megaregions have experienced steady increases in the number of population served per center (figure 4-6) during the past three decades. In 2010, Yangtze has the highest value of population served per center, which indicates that the megaregional centers in Yangtze River Delta has higher level of service and attraction.

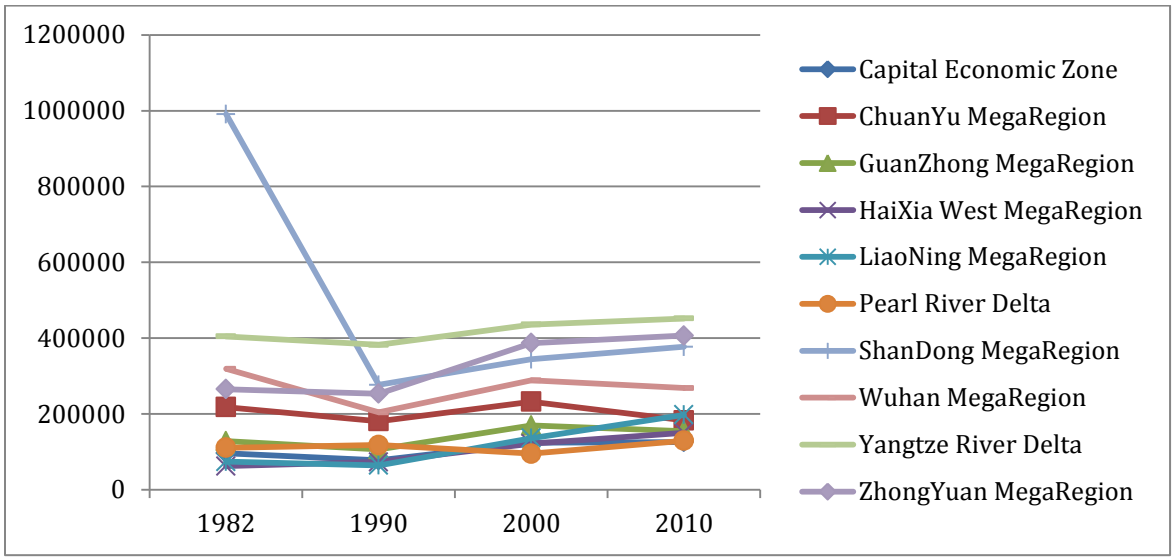


Figure 4-6 Population served per center

- Index *average center's population* (avg_center_pop) calculated the average population size of each megaregional center. Because each center is a standardized 5km*5km grid, this index is also measurement of average population density of the megaregional centers. Relating back to gravity model, this index gives a measurement of the mass or attractiveness of each megaregional center.

The general trend for the average size of megaregional centers has been steady increase (figure 4-7). Only Shandong Megaregion's megaregional centers have decreased in size during the 1982-2010 period. Since megaregional centers are units with the same area, greater population of megaregional center indicates higher densities in megaregional centers. Yangtze River Delta's megaregional centers has the highest size of population, and this indicates that megaregional centers of Yangtze have higher densities, which is more than twice of the megaregional centers in other megaregions.

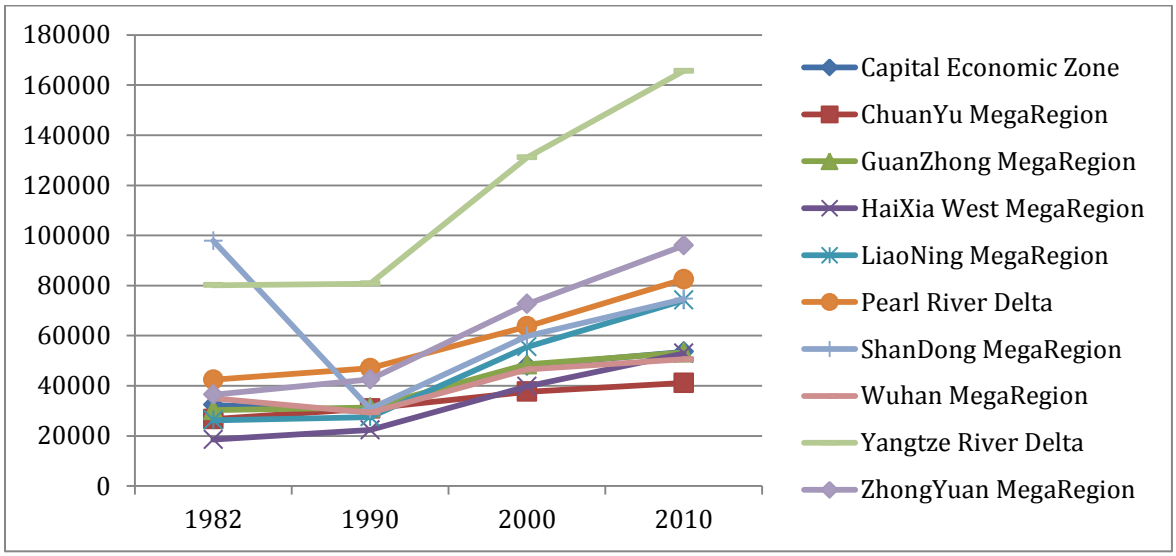


Figure 4-7 Average center's population

Table 4-2 Correlation between alternative polycentricity measures

		ctr_permill_pop	ctr_perkm	pop_per_ctr	avg_ctr_pop	megapopdes
poly	Pearson Corr.	-0.18	-0.2	**0.39****	**0.32****	0.26
	Sig. (2-tailed)	0.256	0.213	**0.012**	**0.041**	0.103
ctr_permill_pop	Pearson Corr.		**0.79*****	**-0.74*****	**-0.55*****	**-0.46*****
	Sig. (2-tailed)		**0.000**	**0.000**	**0.000**	**0.003**
ctr_perkm	Pearson Corr.			**-0.63*****	-0.20	0.06
	Sig. (2-tailed)			**0.000**	0.206	0.704
pop_per_ctr	Pearson Corr.				**0.63*****	**0.43*****
	Sig. (2-tailed)				**0.000**	**0.005**
avg_ctr_pop	Pearson Corr.					**0.84*****
	Sig. (2-tailed)					**0.000**

*** p<0.01, ** p<0.05, * p<0.1

Table 4-2 shows the statistical relationship between the alternative measures of megaregional spatial patterns. Megaregional polycentricity index is positively correlated with pop_per_center and avg_center_pop. Polycentricity is positively related with the development level of megaregional centers (by population density), but not the overall megaergioanl population density. Again these alternative measures are purely quantitative, and they do not indicate any spatial distribution or pattern. Therefore, polycentricity index is more comprehensive in terms of incorperating the spatial pattern of megaregions, and this research will use polycentricity index as the main indicator.

4.2. Assessing changes in mega-regional spatial structure

4.2.1. The change of population density

Figure 4-8 shows the 3D population density evolution from 1982 to 2010. Red color symbolizes the local counties that are classified as megaregional centers. The 1982 and 1990 density maps show a more flattened spatial pattern of population density, while in the 2000 and especially 2010 all ten megaregions exhibit stronger contrasts of population density distribution. The difference between megaregional centers and the surrounding areas are greater after 2000. In 2010, Yangtze River Delta generates multiple concentrations of extremely high-density areas. Most of them are located in the metropolitan of Shanghai, and the average population densities for the central areas of Shanghai are over 30,000 people/km.

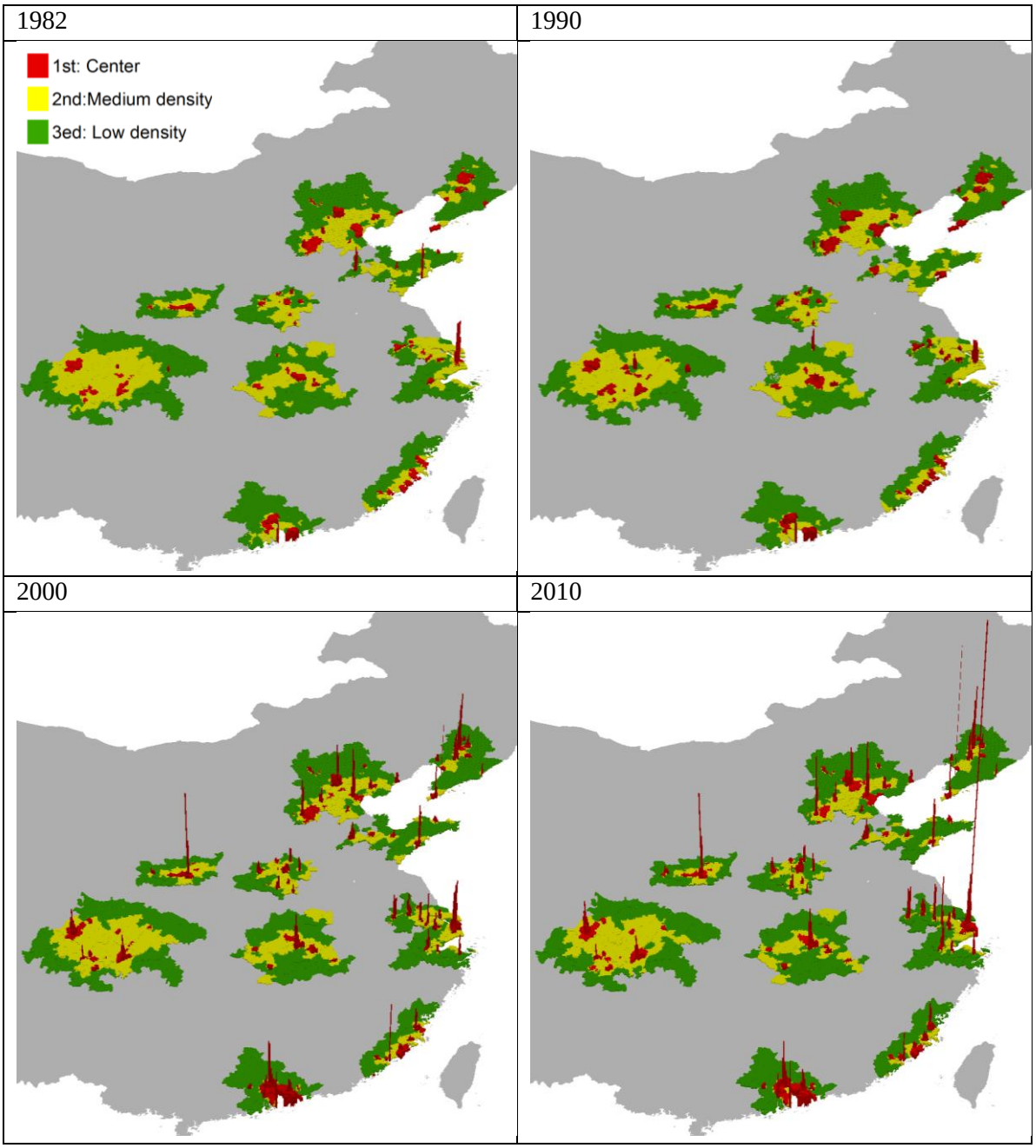
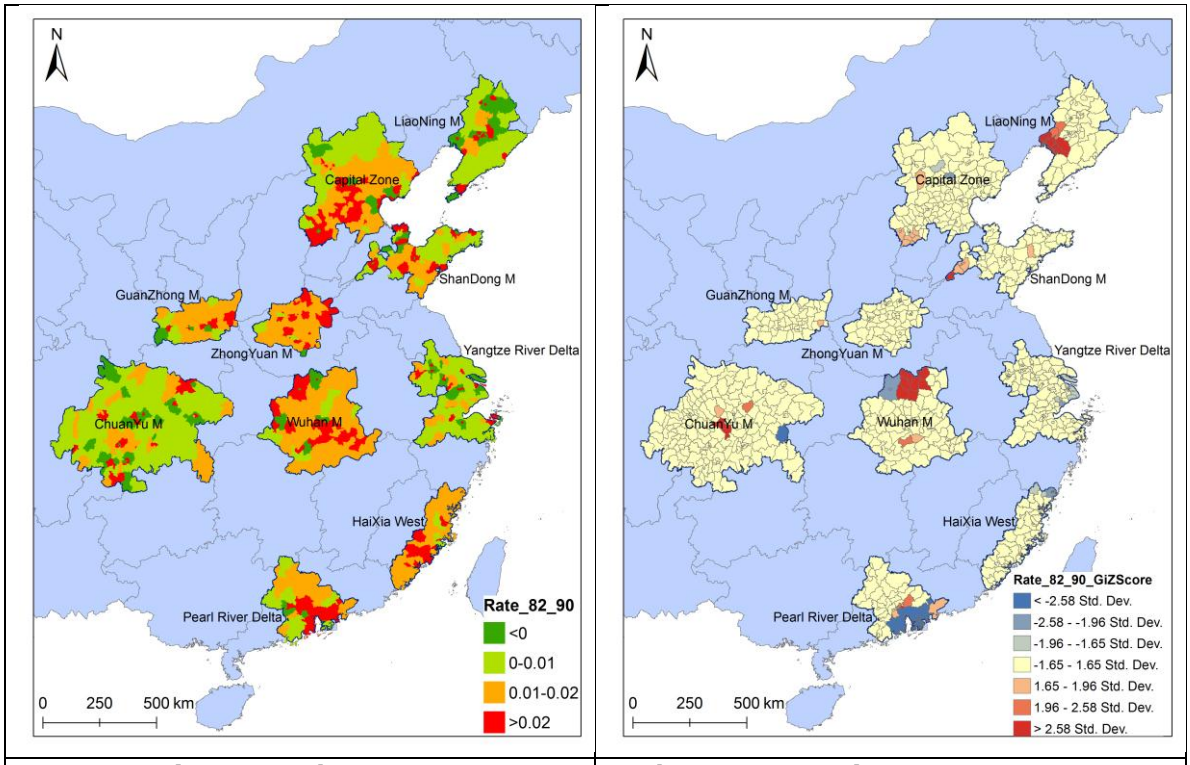


Figure 4-8 Population density 3-D map for all megaregions

4.2.2. The change of population growth rate

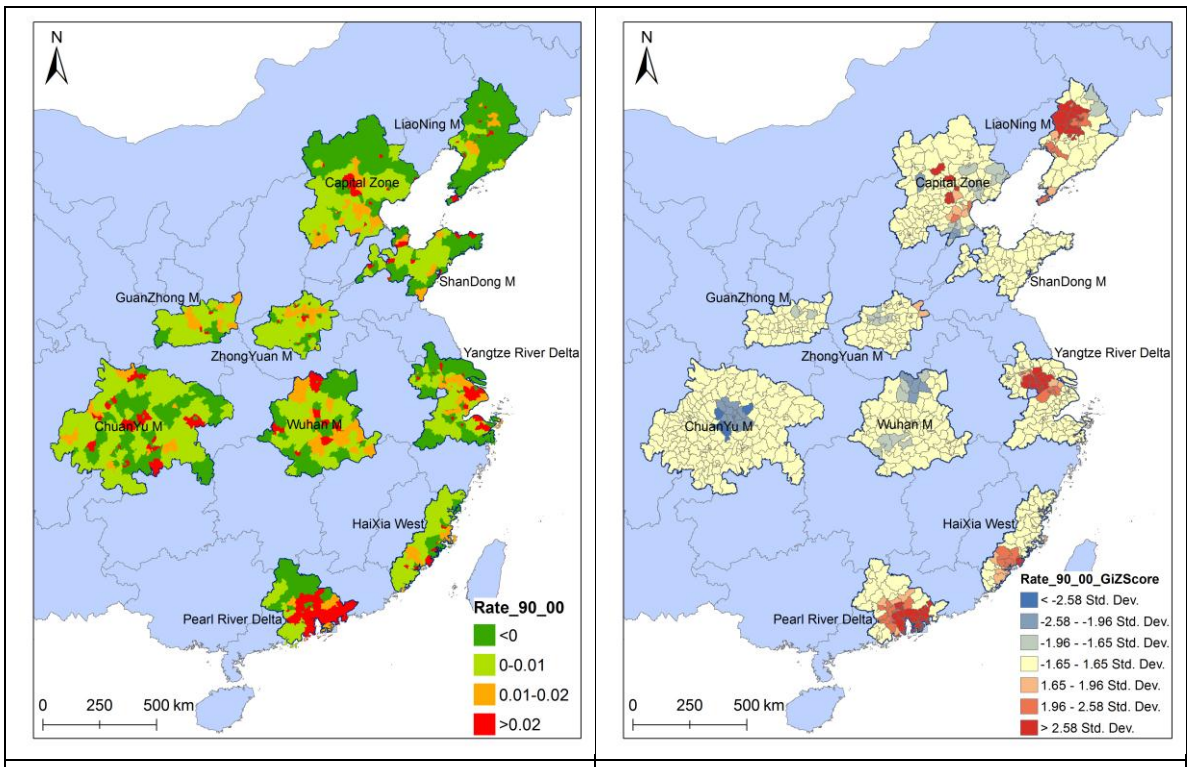


a. Population growth rate | b. Hot spot analysis

Figure 4-9 Analysis of Population growth rate 1982-1990

Figure 4-9 (a) shows the 1982-1990 population growth rates of local counties. GIS spatial statistics tool Spatial Autocorrelation (Moran Index) is used to analyze the spatial patterns of population growth rate. The Spatial Autocorrelation tool evaluates whether the pattern of a set of features and an associated attribute is clustered, dispersed, or random. When the z-score or p-value indicates statistical significance, a positive Moran's I index value indicates tendency toward clustering while a negative Moran's I index value indicates tendency toward dispersion (ArcGIS, 2012b). The spatial autocorrelation for growth rate 1982-1990 generate a z-score of 45.55, $p<0.001$. It thus confirmed that the growth rate exhibit a pattern of spatial clustering.

GIS spatial statistics tool – Hot Spot analysis is used to analyze the spatial clustering of population growth rate. This tool identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot); for statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot) (ArcGIS, 2012a). From 1982 to 1990, there are more hot spots scattered in megaregions (Figure 4-9 b). This corresponds to the calculation results that most megaregions show increased polycentricity indexes during this period.

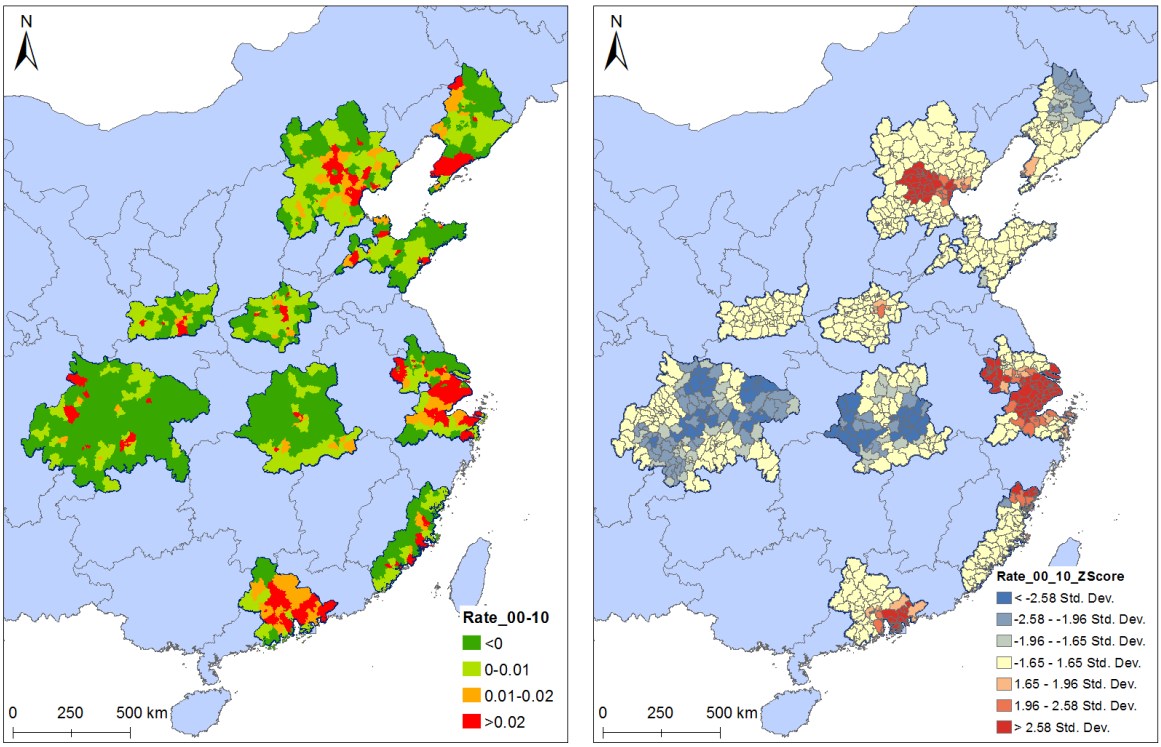


a. Population growth rate

b. Hot spot analysis

Figure 4-10 Analysis of Population growth rate 1990-2000

Figure 4-10 (a) shows the 1990-2000 population growth rates of local counties within the ten megaregions. For the period from 1990 to 2000 (Figure 4-10 b), Hot Spot Analysis indicates that there are more cold spots. Several megaregions show scattered hot spots, and these megaegions are more likely to show increased polycentricity during this period. The spatial autocorrelation for growth rate 1990-2000 generate a z-score of 28.41, $p<0.001$. It thus confirmed that the growth rate exhibit a pattern of spatial clustering.



Population growth rate	Hot spot analysis

Figure 4-11 Analysis of Population growth rate 2000-2010

Figure 4-11 (a) shows the 2000-2010 population growth rates of local counties within the ten megaregions. From 2000 to 2010 (figure 4-11 b), there are more cold spots. Several megaregions show scattered hot spots, and these megaegions are more likely to show increased polycentricity during this period. The spatial autocorrelation for growth rate 2000-2010 generate a z-score of 36.91, $p<0.001$. It thus confirmed that the growth rate exhibit a pattern of spatial clustering.

4.3. Transport network: megaregional level

4.3.1. Transport network density

The first measurement of megaregional transport network calculated the network density, which is defined as:

Network density = $\frac{\sum L*w}{S}$

Where:

L is the length of links,

W is the weight for each segment, which is calculated by design/service speed divided the base year standard speed, which is 40 km/h.

S is the total area of each megaregion.

As mentioned before, most of the recent transport infrastructure projects are highways or speed-increasing upgrades, and therefore the absolute quantity of transport infrastructure length did not change much. Table 4-3 lists the total road length and railway length in the ten megaregions in the starting year of the study period.

Table 4-3 Road and railway in 1982

	Road length (km)	**Rail length (km)**
Capital Economic Zone	10330	3518
ChuanYu MegaRegion	12534	1985
GuanZhong MegaRegion	2757	1008
HaiXia West MegaRegion	3346	325
LiaoNing MegaRegion	4981	1602
Pearl River Delta	4075	538
ShanDong MegaRegion	5035	1063
Wuhan MegaRegion	6944	2000
Yangtze River Delta	6546	1072
ZhongYuan MegaRegion	3487	1031

The statistics for transportation network density for each megaregion are presented in Table 4-4. Figure 4-12 and Figure 4-13 show the evolution of the road and rail transport network density for megaregion from 1982 to 2010. Table 4-5 presents information about the growth rate in road and railway network density for the periods 1982-1990, 1990-2000, and 2000-2010. The most striking aspect of the data is that the growth rates of network densities accelerated during the 2000-2010 periods. This trend is more significant for railway network, due to the large-scale construction of high-speed rail network.

Table 4-4 summary of transport infrastructure by megaregion 1982-2010 (meters/sq km)

Network density (meters/sq km)	**Road**				**Rail**			
	1982	1990	2000	2010	1982	1990	2000	2010
Coastal								
Capital Economic Zone	57	61	101	134	19	25	37	65
LiaoNing MegaRegion	55	64	93	132	18	21	27	67
ShanDong MegaRegion	71	71	104	184	15	18	24	64
Yangtze River Delta	70	70	124	200	11	15	23	88
HaiXia West MegaRegion	63	63	87	146	6	7	9	31
Pearl River Delta	56	56	87	148	7	9	12	32
Inland area								
ChuanYu MegaRegion	47	47	64	103	7	9	11	25
GuanZhong MegaRegion	50	50	68	122	18	22	30	42
ZhongYuan MegaRegion	59	59	97	159	18	22	36	52
Wuhan MegaRegion	47	47	67	132	14	17	24	60
10 megaregion average	55	56	85	137	13	16	23	51

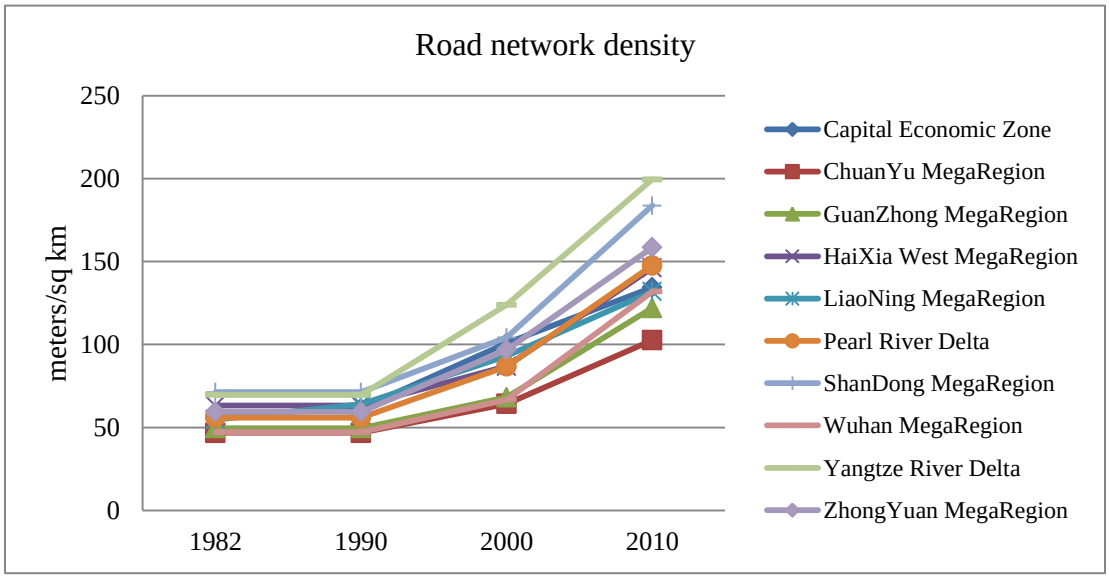


Figure 4-12 Summary of road network density (meters/sq km) by megaregion

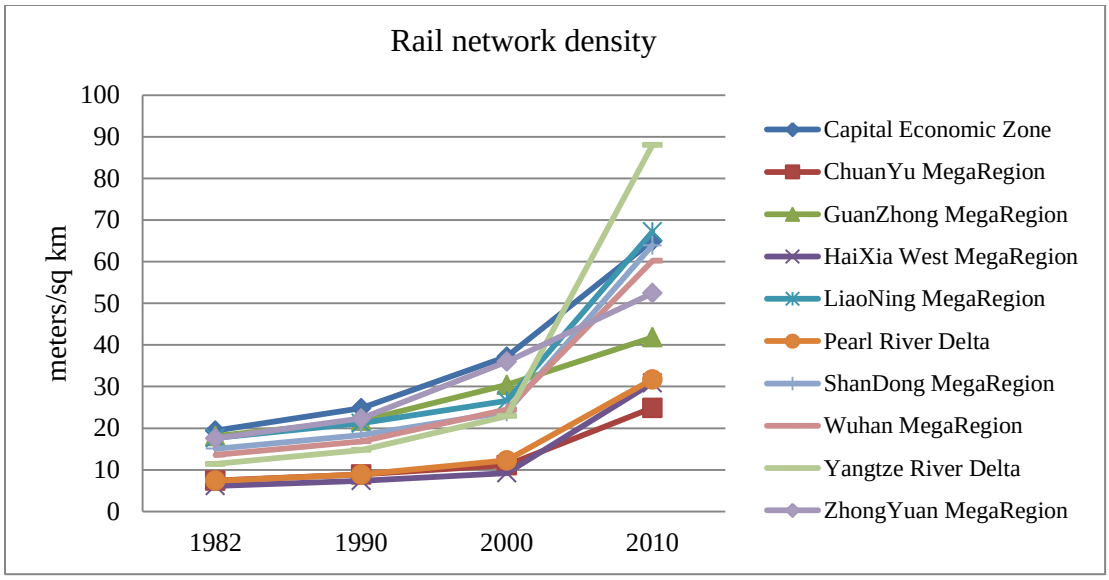


Figure 4-13 Summary of rail network density (meters/sq km) by megaregion

Table 4-5 Growth rate of road and railway network density

Growth rate	**Growth rate of road network density**			**Growth rate of rail network density**		
	82-90	90-00	00-10	82-90	90-00	00-10
Coastal						
Capital Economic Zone	0.08	0.64	0.33	0.28	0.50	0.75
LiaoNing MegaRegion	0.17	0.46	0.42	0.20	0.25	1.53
ShanDong MegaRegion	0.00	0.46	0.76	0.22	0.30	1.68
Yangtze River Delta	0.00	0.78	0.61	0.29	0.55	2.84
HaiXia West MegaRegion	0.00	0.38	0.68	0.20	0.25	2.35
Pearl River Delta	0.00	0.55	0.70	0.20	0.38	1.58
Inland area						
ChuanYu MegaRegion	0.00	0.38	0.60	0.20	0.25	1.24
GuanZhong MegaRegion	0.00	0.38	0.79	0.20	0.40	0.38
ZhongYuan MegaRegion	0.00	0.63	0.64	0.27	0.61	0.46
Wuhan MegaRegion	0.00	0.41	0.98	0.24	0.45	1.46
10 megaregion average	0.02	0.51	0.65	0.23	0.40	1.43

While all coastal megaregions have more developed road network in term of network density, in 2010 the road network densities of two of the coastal megaregions dropped below the average level for all the 10 megaregions. Road network densities in inland megaregions are generally lower than the 10 megaregional average network density. Zhongyuan megaregion is the only inland megaregion with road network densities higher than the 10 megaregional average network density from 1982 to 2010.

During the 2000-2010 period, although Guanzhong megaregion and Wuhan megaregion have exhibited growth rates of road network density higher than the 10 megaregional average, their road network density levels are still lagging behind the 10 megaregional average rate.

Railway network density growths are more significant in the coastal megaregions, and this is due to the fact that large share of the new high-speed railways are constructed in the coastal areas. The gap of stock of railway infrastructure between coastal megaregions and inland megaregions became more significant starting after 2000.

From 2000 to 2010, five out of six coastal megaregions show growth rates of railway network density higher than the 10 megaregional average rate, and only one inland megaregion has higher rate of railway network density growth during that period. This further confirms that the recent investment in railway and especially high-speed railway is strongly biased toward the coastal areas. In addition, Wuhan megaregion is the only inland megaregion having growth rates of railway network density higher than the 10 megaregional average growth rate for the three consecutive periods.

Two-way ANOVA

Transport network densities were subjected to a two-way analysis of variance having two levels of location (coastal, inland), and four levels of time (1982, 1990, 2000 and 2010). Table 4-6 summarizes the two-way ANOVA results with fixed effects of coastal location, year, and the interaction between coastal location and time.

Table 4-6 Summary of ANOVA analysis for road and rail network density

Fixed effects	road density		rail density		rate: road density		rate: rail density	
	F	sig	F	sig	F	sig	F	sig
coastal	15.00***	.000	0.18	.676	0.03	.863	3.82*	.062
year	64.74***	.000	19.67***	.000	62.78***	.000	22.16***	.000
coastal#year	0.73	.544	0.96	.423	2.73*	.086	4.53**	.021
R^2/adj. R^2	.877	.850	.685	.616	.845	.813	.738	.683

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Road network density (Figure 4-14): A two-way analysis of variance of road network density yielded a main effect for the coastal location, $F(1,39)=15$, $p<0.01$, such that the average road network density was significant higher for coastal megaregions than for non-coastal region. The main effect of year yielded an F ratio of $F(3,39)=64.74$ $p<0.01$, indicating that road network densities grew continuously. The interaction term between coastal location and year is non-significant, $F(3,39)=0.73$, $p>0.1$.

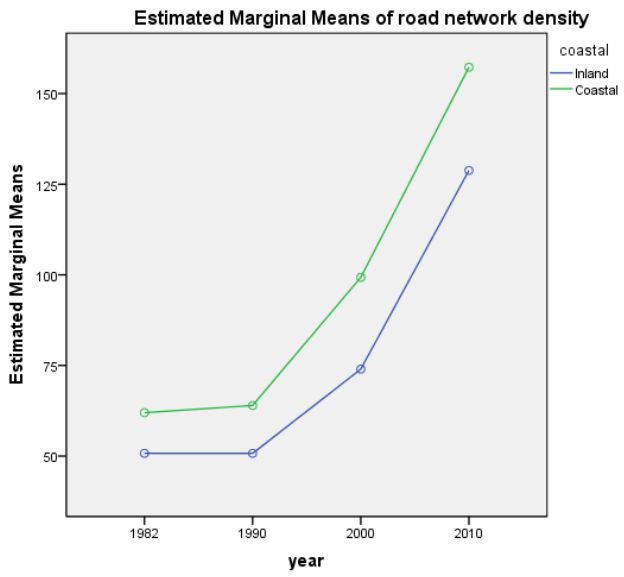


Figure 4-14 Two way ANOVA for road network density

Railway network density (Figure 4-15): The main effect of coastal location is non-significant, $F(1,39)=0.18$, $p>0.1$. The main effect of time yielded an F ratio of $F(3,39)=19.67$ $p<0.01$, indicating that railway network densities grew continuously. The interaction term between coastal location and year is non-significant, $F(3,39)=0.96$, $p>0.1$.

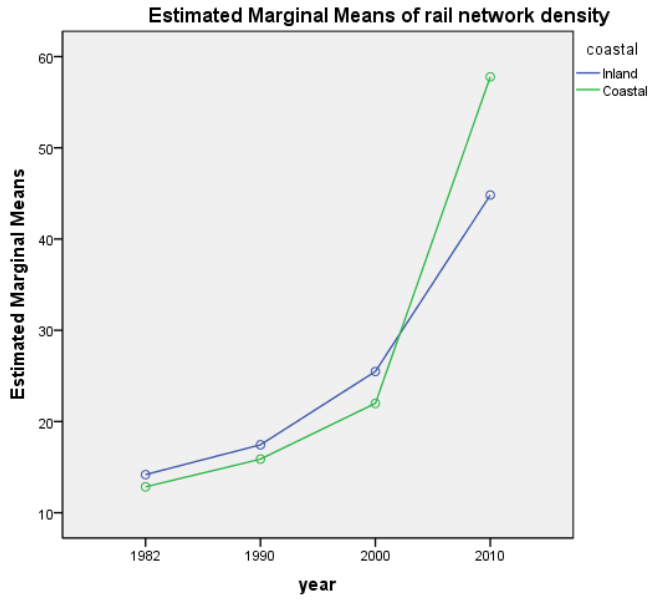


Figure 4-15 Two way ANOVA for rail network density

Road network density growth rate (Figure 4-16): the main effect of coastal location is non-significant, $F(1,29)=0.03$, $p>0.1$. The main effect of year yielded an F ratio of $F(2,29)=62.78$ $p<0.01$, indicating that the growth rates of road density have been accelerated continuously during the past three decades. The interaction effect is significant, $F(2,29)=2.73$ $p<0.1$, indicating that the time effect is stronger for non-coastal areas than for coastal areas.

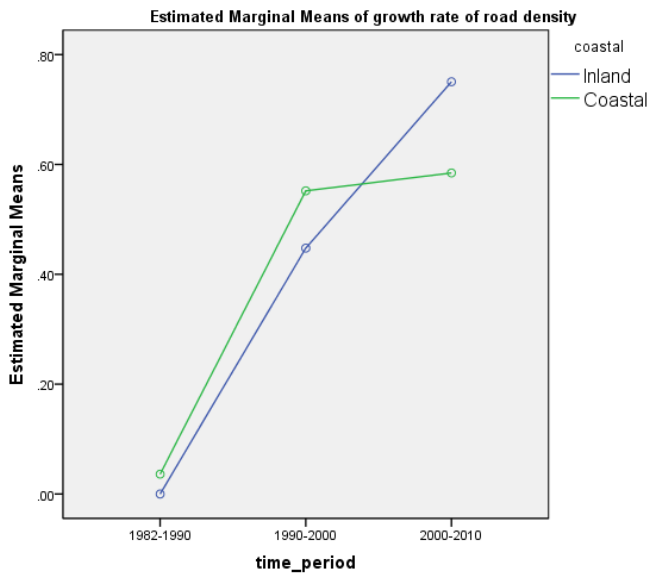


Figure 4-16 Two way ANOVA for the growth rate of road network density

Rail network density growth rate (Figure 4-17): the main effect of coastal location yielded an F ratio of $F(1,29)=3.82$, $p<0.1$, indicating that the that the growth rates of road density are higher in coastal areas than in inland areas. The main effect of year yielded an F ratio of $F(2,29)=22.161$ $p<0.01$, indicating that the growth rates of rail density have been accelerated continuously during the past three decades. The interaction effect is significant, $F(2,29)=4.53$ $p<0.05$, indicating that the time effect is stronger for coastal areas than for non-coastal areas.

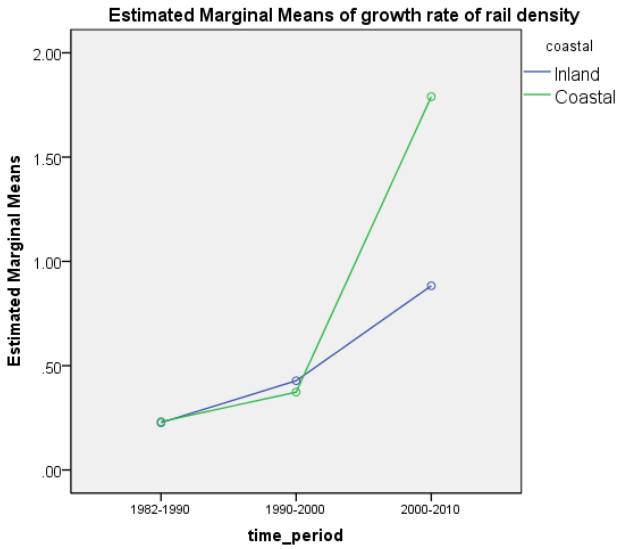


Figure 4-17 Two way ANOVA for the growth rate of rail network density

4.3.2. Transport infrastructure per capita

The second measurement of megaregional transport network calculated the transport infrastructure length per capita, which is defined as :

Network density = $\frac{\sum L*w}{P}$

Where:

L is the length of links,

W is the weight for each segment, which is calculated by design/service speed divided the base year standard speed, which is 40 km/h.

P is the total population of each megaregion.

The statistics for transportation stock per capita for each megaregion are presented in Table 4-7, Figure 4-13 and Figure 4-14, which shows road and rail link length per capita by megaregion and the average for the 10 megaregions for 1982, 1990, 2000 and 2010. Table 4-8 presents information about the growth in road and railway network density for

the periods 1982-1990, 1990-2000, and 2000-2010. Like the measurement of transport network density, the most striking aspect for transport link per capita is that the growth rates accelerated during the 2000-2010 periods. This trend is more significant for railway network, due to the large-scale construction of high-speed rail network.

Four of the six coastal megaregions have more developed road network in term of transport link length per capita from 1982 to 2010. Road network densities in inland megaregions are generally lower than the 10 megaregional average network density. However, from 2000 to 2010 road link length per capita in three of the four inland megaregions rose to above the 10 megaregion average level.

Railway link length per capita is generally higher than inland megaregions. From 1982 to 2000, three inland megaregions have road network densities higher than the 10 megaregional average network density. However from 2000 to 2010, only two inland megaregions remain their higher than average railway link length per capita level.

The most striking fact about road length per capita is that during 1982-1990, all the ten megaregions have negative growth rates, which indicates that the expansion or upgrade of road network is lagging behind after the growth of population. During 1990-2000, most coastal regions experienced growth rate of road lengthen per capita higher than the 10 megaregional average. This trend shifted during 2000-2010, with three inland megaregions having growth rate of road length per capita higher than the 10 megaregional average rate.

In terms of the growth rate of railway lengthen per capita, before 2000 more inland regions experienced growth rate of railway lengthen per capita higher than the 10 megaregional average. This trend shifted during 2000-2010, with four coastal megaregions having growth rate of railway length per capita higher than the 10 megaregional average rate.

Table 4-7 Stock of transport infrastructure per capita by megaregion 1982-2010 (meters/ thousand people)

	Road length per capita				**Rail length per capita**			
	1982	1990	2000	2010	1982	1990	2000	2010
Coastal								
Capital Economic Zone	188	177	259	303	64	71	95	146
LiaoNing MegaRegion	198	208	286	370	64	69	81	188
ShanDong MegaRegion	154	140	189	316	33	36	43	110
Yangtze River Delta	105	100	152	185	17	21	28	82
HaiXia West MegaRegion	187	162	189	268	18	19	20	57
Pearl River Delta	159	128	126	166	21	21	18	36
Inland								
ChuanYu MegaRegion	134	125	163	273	21	24	28	66
GuanZhong MegaRegion	164	143	175	290	60	63	78	100
ZhongYuan MegaRegion	119	103	151	227	35	39	56	75
Wuhan MegaRegion	145	129	167	349	42	46	61	159
10 megaregion average	148	136	181	263	35	39	48	97

Table 4-8 growth rate of transport infrastructure per capita by megaregion

Growth rate	**% of road length per capita**			**% of rail length per capita**		
	1982-1990	1990-2000	2000-2010	1982-1990	1990-2000	2000-2010
Coastal						
Capital Economic Zone	-0.06	0.46	0.17	0.12	0.34	0.54
LiaoNing MegaRegion	0.05	0.38	0.29	0.08	0.18	1.31
ShanDong MegaRegion	-0.09	0.35	0.67	0.11	0.20	1.53
Yangtze River Delta	-0.05	0.53	0.22	0.23	0.33	1.92
HaiXia West MegaRegion	-0.14	0.17	0.42	0.03	0.06	1.83
Pearl River Delta	-0.20	-0.01	0.32	-0.01	-0.14	1.00
Inland						
ChuanYu MegaRegion	-0.07	0.31	0.67	0.12	0.19	1.35
GuanZhong MegaRegion	-0.13	0.22	0.66	0.04	0.24	0.28
ZhongYuan MegaRegion	-0.13	0.46	0.50	0.10	0.45	0.33
Wuhan MegaRegion	-0.11	0.30	1.08	0.10	0.34	1.59
10 megaregion average	-0.09	0.32	0.50	0.09	0.22	1.17

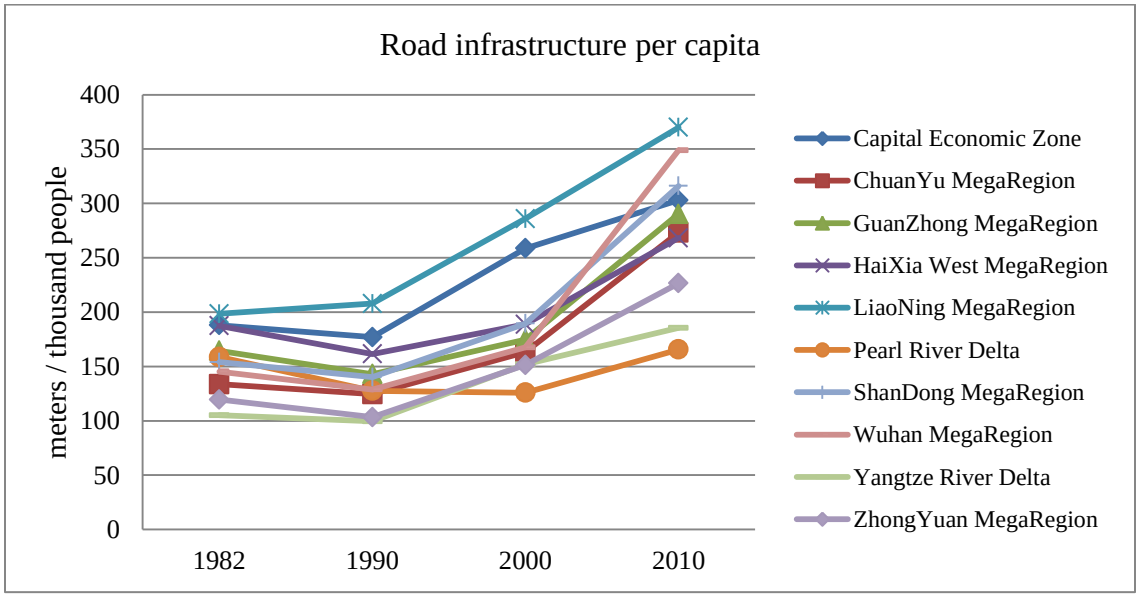


Figure 4-18 Summary of road length per capita by megaregion (meter/1,000 people)

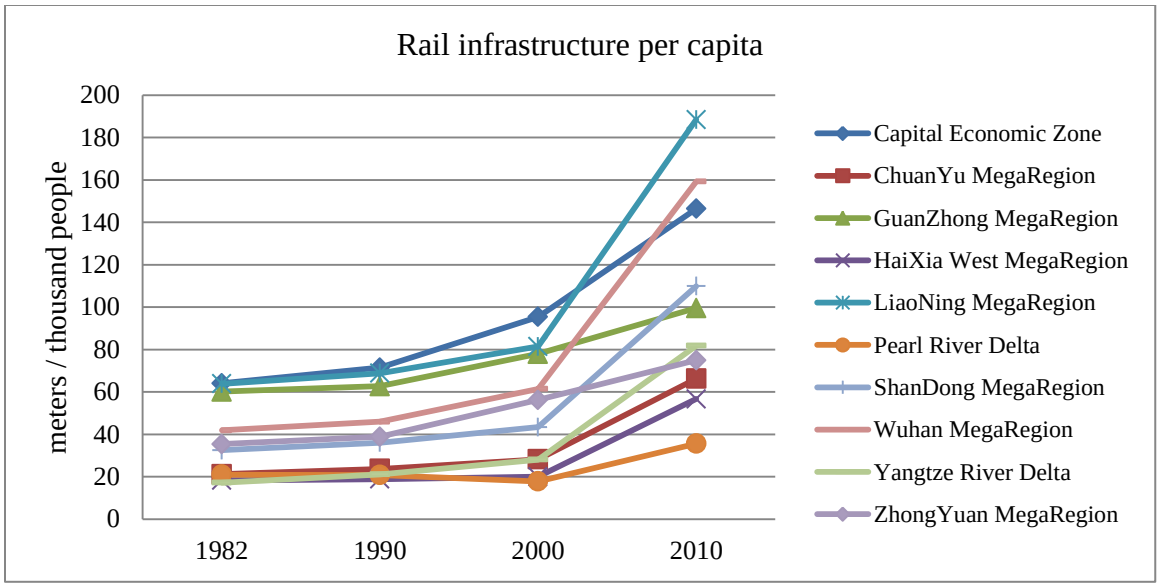


Figure 4-19 Summary of rail length per capita by megaregion (meter/1,000 people)

Two-way ANOVA

Transport link length per capita is subjected to a two-way analysis of variance having two levels of location (coastal, inland), and four levels of time (1982, 1990, 2000 and 2010). Table 4-9 summarizes the two-way ANOVA results with fixed effects of coastal location, year, and the interaction between coastal location and time.

Table 4-9 Summary of two way ANOVA

Fixed effects	road capita		rail capita		rate: road capita		rate: rail capita	
	F	sig	F	sig	F	sig	F	sig
coastal	1.33	.258	0.08	.784	4.12*	.054	0.68	.417
year	16.12***	.000	7.58***	.001	39.04***	.000	23.91***	.000
coastal#year	0.58	.632	0.05	.986	4.79**	.018	1.95	.164
R^2/adj. R^2	.610	.525	.433	.309	.782	.736	.714	.654

Road length per capita (Figure 4-20): The main effect of coastal location is non-significant, $F(1,39)=1.33$, $p>0.1$. The main effect of year yielded an F ratio of $F(3,39)=16.12$ $p<0.01$, indicating that road length per capita grew continuously. The interaction term between coastal location and year is non-significant, $F(3,39)=0.58$, $p>0.1$.

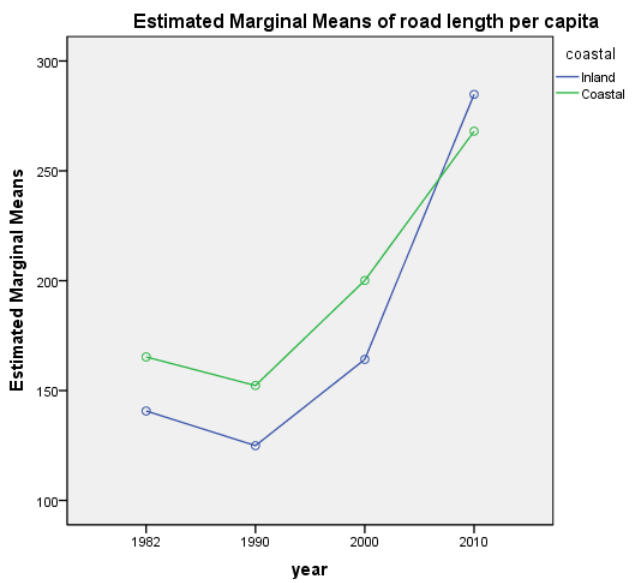


Figure 4-20 Two way ANOVA for road length per capita

Rail length per capita (Figure 4-21): The main effect of coastal location is non-significant, $F(1,39)=0.08$, $p>0.1$. The main effect of year yielded an F ratio of $F(3,39)=7.58.12$ $p<0.01$, indicating that rail length per capita grew continuously. The interaction term between coastal location and year is non-significant, $F(3,39)=0.05$, $p>0.1$.

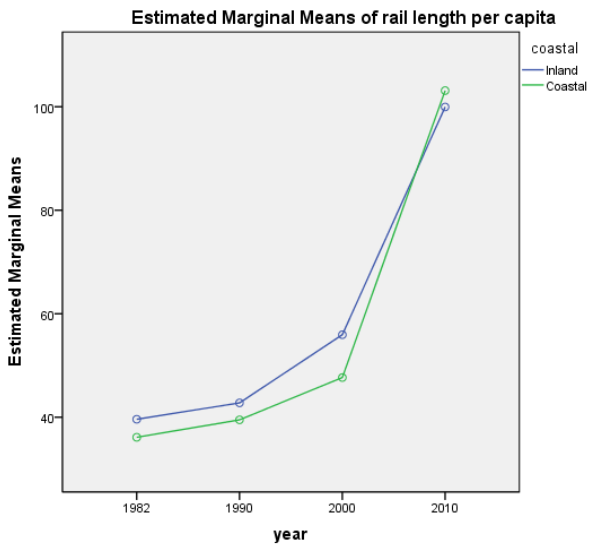


Figure 4-21 Two way ANOVA for rail length per capita

Road length per capita growth rate (Figure 4-22): the main effect of coastal location yielded an F ratio of $F(1,29)=4.12$, $p<0.1$, indicating that the that the growth rates of road road length per capita are higher in inland areas than in coastal areas. The main effect of year yielded an F ratio of $F(2,29)=39.04$ $p<0.01$, indicating that the growth rates of road length per capita have been accelerated continuously during the past three decades. The interaction effect is significant, $F(2,29)=4.79$ $p<0.05$, indicating that the time effect is stronger for inland areas than for coastal areas.

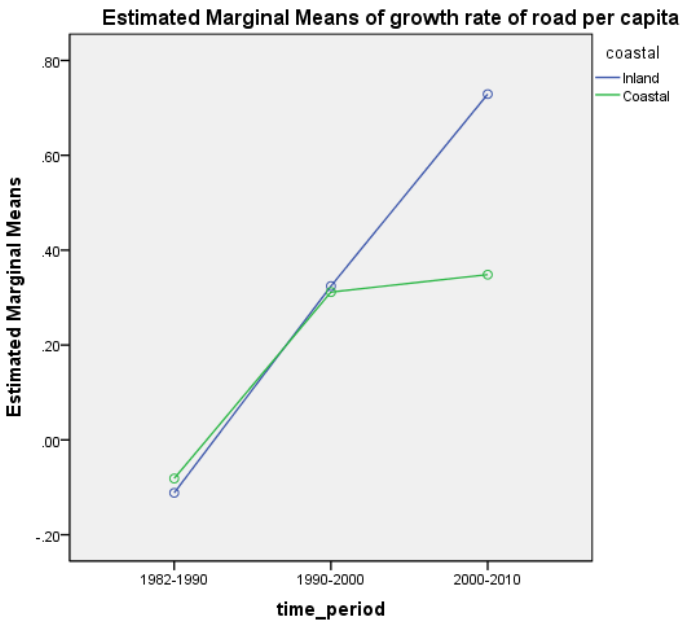


Figure 4-22 Two way ANOVA for growth rate of road length per capita

Rail length per capita growth rate (Figure 4-23): the main effect of coastal location is non-significant, $F(1,29)=0.68$, $p>0.1$. The main effect of year yielded an F ratio of $F(2,29)=12.91$ $p<0.01$, indicating that the growth rates of rail length per capita have been accelerated continuously during the past three decades. The interaction effect is non-significant, $F(2,29)=1.95$ $p>0.1$.

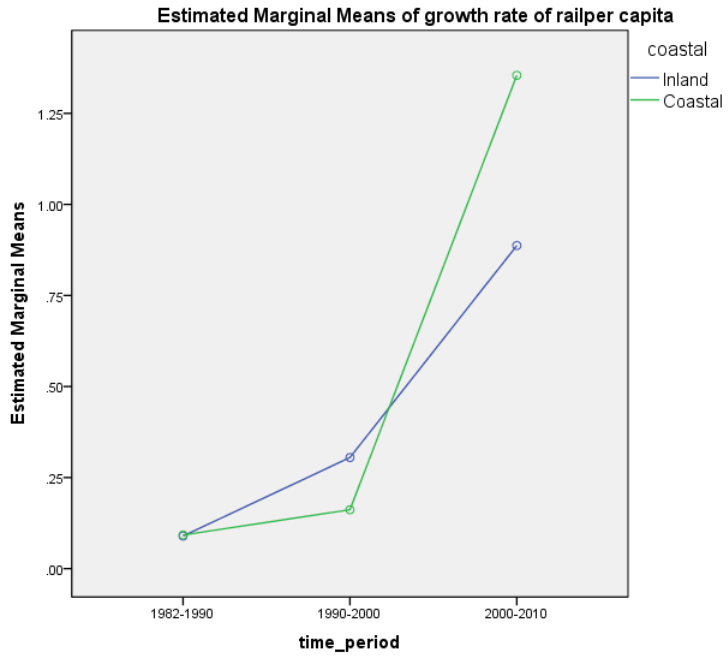


Figure 4-23 Two way ANOVA for growth rate of rail length per capita

4.3.3. Transport network spatial structure

Table 4-10 Area of Road network ellipse

	Road Network Ellipse (sq. km)				
Megaregion	1982	1990	2000	2010	1982-2010
Capital Economic Zone	78585	77326	70149	73707	-6.21%
ChuanYu MegaRegion	96753	96425	96753	93500	-3.36%
GuanZhong MegaRegion	22797	22716	22797	23073	1.21%
HaiXia West MegaRegion	43954	43797	43954	35742	-18.68%
LiaoNing MegaRegion	37579	35789	34454	30525	-18.77%
Pearl River Delta	51210	28247	47557	26113	-49.01%
ShanDong MegaRegion	50535	50732	55417	53478	5.82%
Wuhan MegaRegion	70286	70377	73264	66920	-4.79%
Yangtze River Delta	55482	55482	52186	55735	0.46%
ZhongYuan MegaRegion	25588	25488	25552	26102	2.01%

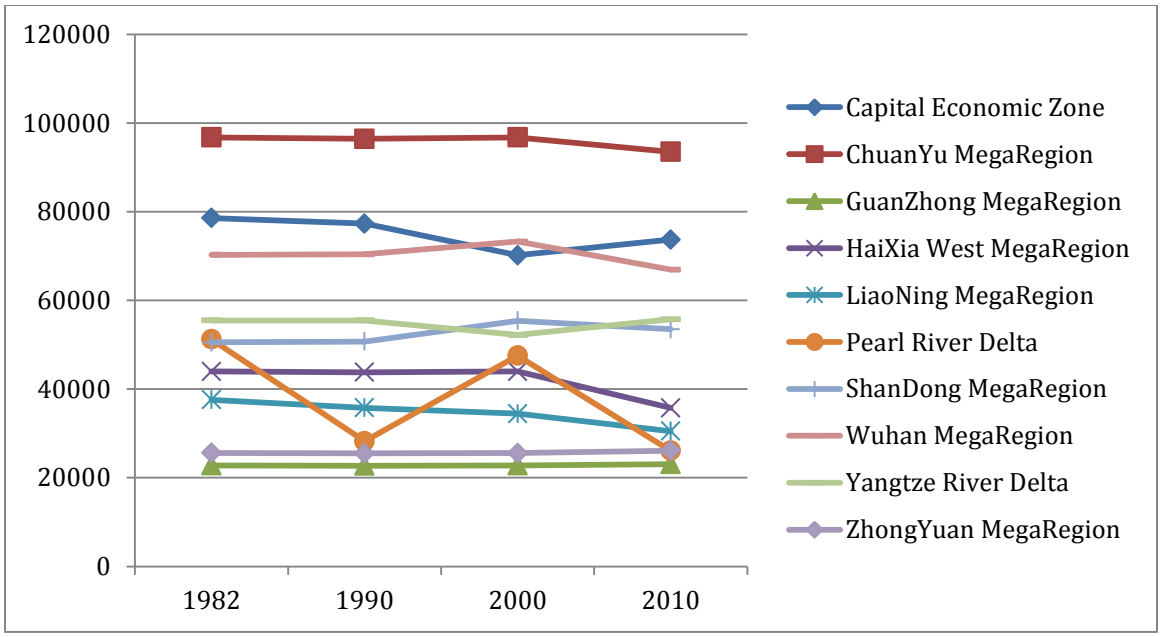


Figure 4-24 Area of Road network ellipse

Table 4-11 Area of rail network ellipse

	Rail Network Ellipse (sq. km)				
Megaregion	1982	1990	2000	2010	1982-2010
Capital Economic Zone	59597	58956	59528	52518	-11.88%
ChuanYu MegaRegion	66580	66580	65915	64259	-3.49%
GuanZhong MegaRegion	18910	18910	19952	19565	3.46%
HaiXia West MegaRegion	10692	10692	10692	17399	62.73%
LiaoNing MegaRegion	38814	39451	42391	31197	-19.62%
Pearl River Delta	19898	19898	19961	15622	-21.49%
ShanDong MegaRegion	38220	39207	41852	26774	-29.95%
Wuhan MegaRegion	66629	66647	69434	59458	-10.76%
Yangtze River Delta	41385	40230	39292	32230	-22.12%
ZhongYuan MegaRegion	22848	22718	21874	21254	-6.98%

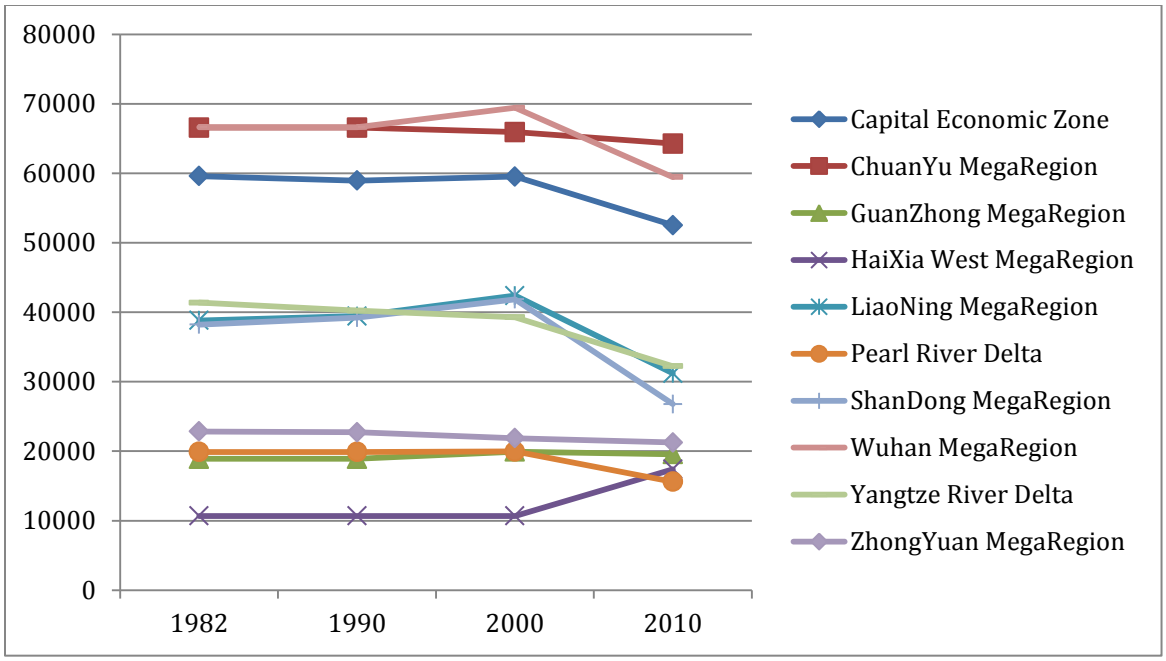


Figure 4-25 Area of rail network ellipse

4.4. Transport network: local level

This section assesses transport network at the local level through two measurements: connectivity and accessibility.

It should be noted megaregions are of different sizes ranging from 52,000 sq. km to 267,000 sq. km. The differences of the 10 megaregions' geographical span make the comparison between megaregions less meaningful. Therefore the analysis should focus on the cross-sectional comparisons of the local units within each megaregion and between megaregions of similar sizes, and the longitudinal comparisons across 1982 to 2010, which will provide meaningful information about the differentiations and changes of regional connectivity of the ten megaregions.

4.4.1. Network connectivity

Figure 4-26 illustrates the evolution of local connectivity to megaregional activities by road from 1982 to 2010. Figure 4-27 illustrates the evolution of local connectivity to megaregional activities by rail from 1982 to 2010. The connectivity measures of the two modes are rather consistent with each other. Statististics confirm the strong correlation between accessibility by road and by rail.

Consistent with the previous analysis, the most significant change happens between 2000 and 2010. In 2010, the within-megaregion connectivity for most megaregions is below 3 hours by road or by rail. Chuanyu megaregion shows longer travel times not only due to its large territory, but also its mountainous geographic feature, but it nevertheless exhibits significant improvement in terms of connectivity from 1982 to 2010.

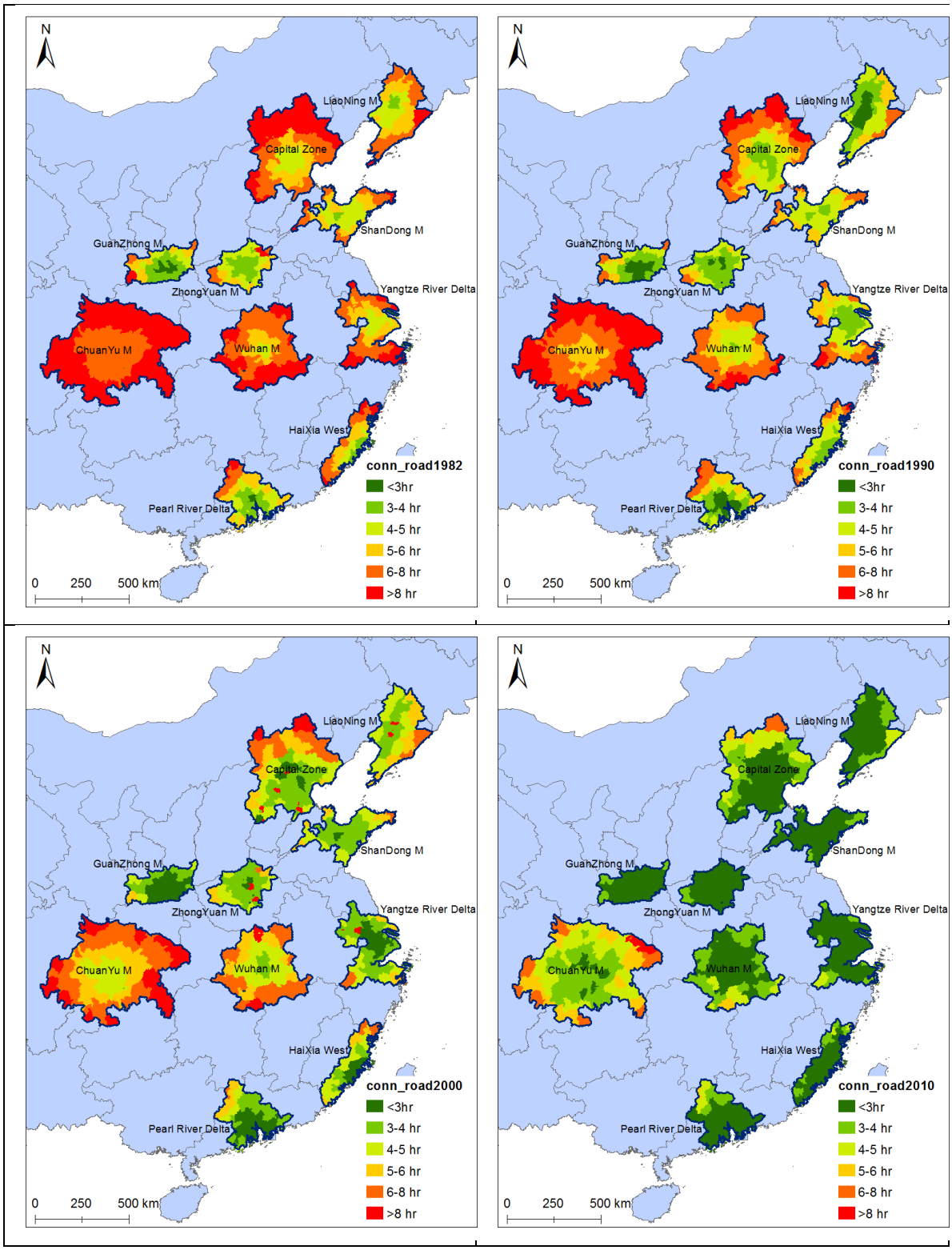


Figure 4-26 Road network connectivity 1982-2000

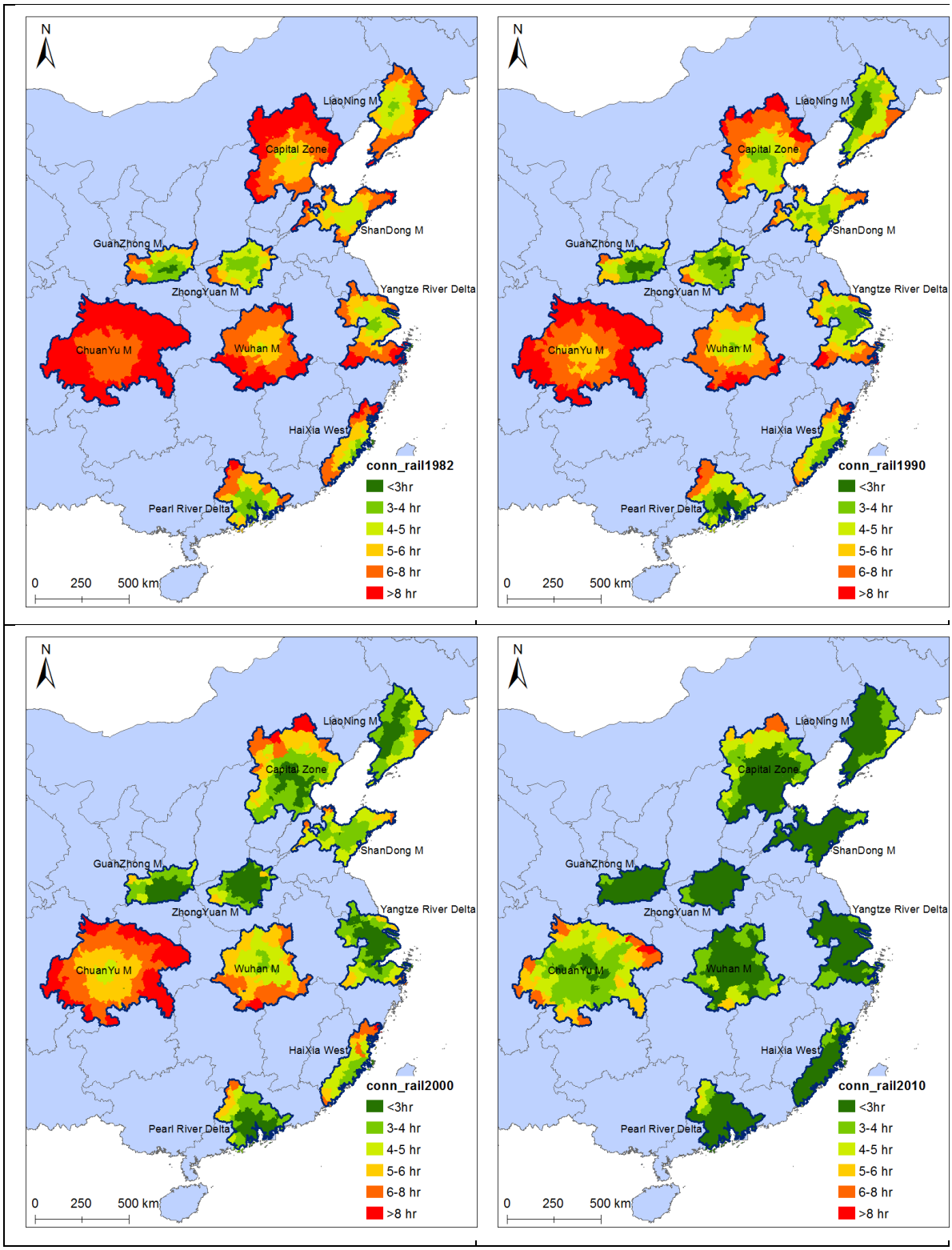


Figure 4-27 Rail network connectivity 1982-2000

4.4.2. Network accessibility

Figure 4-28 illustrates the evolution of local accessibility to megaregional activities by road from 1982 to 2010. Figure 4-29 illustrates the evolution of local accessibility to megaregional activities by rail from 1982 to 2010. Consistent with the previous analysis, the most significant change occurs between 2000 and 2010.

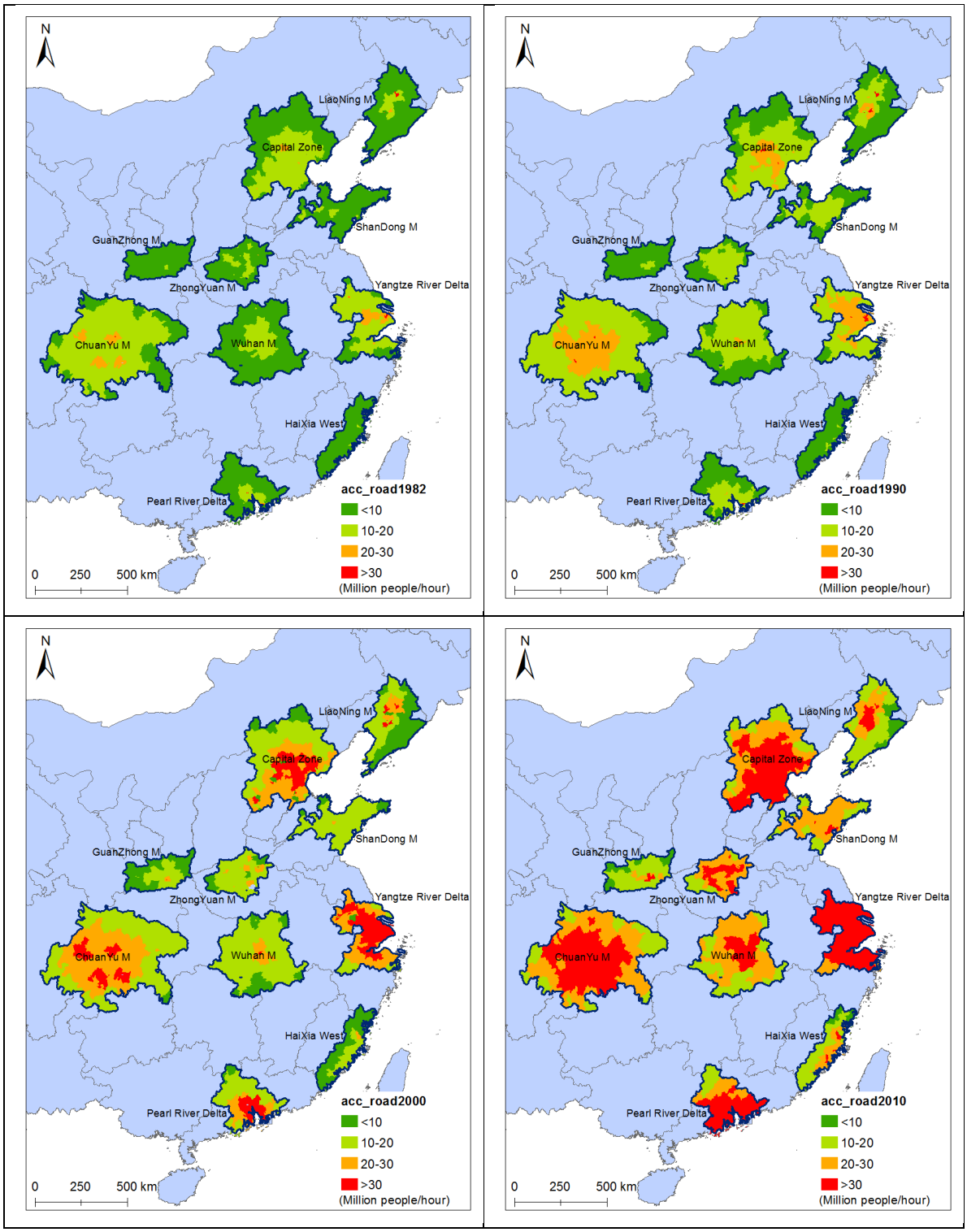


Figure 4-28 Road Accessibility 1982-2000

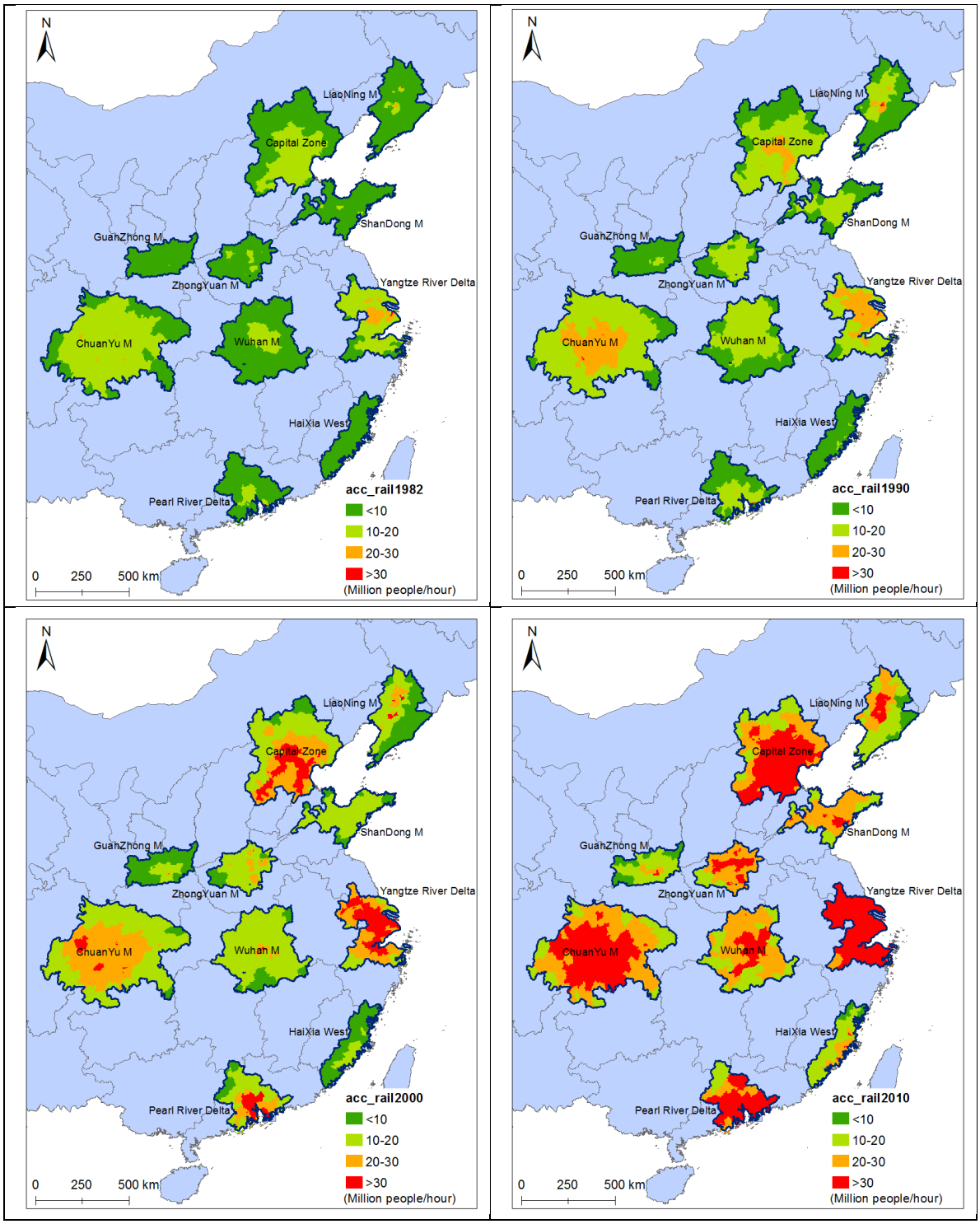


Figure 4-29 Rail Accessibility 1982-2000

4.5. Assessing the impacts of mega-regional transport infrastructure: megaregional level

This section tries to explore the relationship between transport network and megaregional spatial patterns at the megaregional level. Three sets of models (Table 4-12) are run to test to possible causal relationship between megaregional transport infrastructure and megaregional spatial patterns measured by polycentricity. The first model uses transport network density in the base year as explanatory variables; the second model uses transport infrastructure stock per capita in the base year as explanatory variables; the third model uses the size of the standard ellipse of transport network as explanatory variables. The model finds that railway network characteristics are positively significant in affecting the polycentric spatial patterns of megaregions: railway density is positively significant at one-tail 0.1 level (p=0.101); railway length per capital is positively significant at one-tail 0.1 level (p=0.128); railway network ellipse size is positively significant at the one-tail 0.01 level (p=0.0183). Road network density and road length per capita are negative, but not significant, and road network ellipse size is negatively significant (p=0.0956). The results indicate railway has stronger positive effects for regional spatial patterns. Denser and more expanded railway network are more likely to create more polycentric spatial patterns.

The dummy variable coastal is positively significant, and thus it confirms that coastal megaregions are more polycentric compared with inland megaregions. This model also confirms that the measurement and calculation method of polycentricity is not subject to megaregion density variations.

Table 4-12 Polycentricity and megaregional transport network

polycentricity	**Model 1**		**Model 2**		**Model 3**	
	coef	pval	coef	pval		
poly_lag	-0.103	0.588	-0.138	0.491	-0.171	0.352
coastal	0.207**	0.026	0.216**	0.045	0.179**	0.025
megapopdes	0.000164	0.552	0.000258	0.327	0.000297	0.158
roaddes_lag	-0.000738	0.833				
raildes_lag	0.0109	0.101				
roadcap_lag			-0.00110	0.521		
railcap_lag			0.00431	0.128		
road_ellip_lag					-5.07e-12*	0.0956
rail_ellip_lag					8.71e-12**	0.0183
Constant	0.248	0.129	0.348	0.244	0.28	0.123
Observations	30		30		30	
R-squared	0.352		0.299		0.351	

Y: polycentricity *** p<0.01, ** p<0.05, * p<0.1

Further regressions are run to test the relationships between alternative polycentricity measures and megaregioanl transport network measures. The dependent variable is set to 1) center_per_millpop, 2) center_perkm, 3) pop_per_center, and 4) avg_center_pop; for each dependent variable; three sets of models are run using different sets of megaregional level transport measure as explanatory variables: 1) road/rail network density; 2) road/rail per capita; and 3) road/rail network standard deviational ellipse size. Two models (Table 4-13) show significant significant results of transport network explanatory variables. The results of other models with no significant transport variables are shown in Appendix B.

Road/rail network ellpise size is significant in explaning two alternative polycentricity measures: Population per center and average center's population (Table 4-13). Railway

network ellipse size is positively significant (p<0.05) for both polycentricity measures, while road network ellipse is not significant for population per center (p=0.164), and negatively significant for average center's population (p=0.062). The regression results for alternative polycentricity measures indicate that a more extended railway network contributed to higher level of service or development of the centers for the whole megaregion, and similarly the mass or attractiveness of megaregional centers are stronger.

Table 4-13 Alternative polycentricity measure and megaregional transport network

Y:	**pop_per_center**		**avg_center_pop**	
VARIABLES	coef	pval	coef	pval
coastal	-50,135*	0.088	3,833	0.539
megapopdes	400.8***	0.000	128.0***	0.000
road_ellip_lag	-1.56e-06	0.164	-4.74e-07*	0.062
rail_ellip_lag	2.79e-06**	0.046	6.60e-07**	0.040
pop_per_center_lag	0.228***	0.009		
avg_center_pop_lag			0.210	0.298
Constant	-33,502	0.558	-20,357	0.118
Observations	30		30	
R-squared	0.706		0.807	

*** p<0.01, ** p<0.05, * p<0.1

4.6. Assessing the impacts of mega-regional transport infrastructure: local level

This part will look the impacts of transport infrastructure for regional growth at the local level. Regional growth will be assessed by two measures: population density and population growth rate. The dataset is composed of four time points – 1982, 1990, 2000 and 2010, and thus three time periods – 1982-1990, 1990-2000 and 2000-2010.

The main explanatory variables will be accessibility by road and accessibility by rail. In order to explore the causal effects of transport accessibility, this research will employ the Granger-causality concept, and use accessibility level in the base year (lagged value) as the main explanatory variables. Three sets of regressions will be run to analyze the differential effects of transportation infrastructure (road and rail) on urban growth:

1. **General** model: compares between road accessibility and railway accessibility, and does not distinguish between different types of regions.

OLS

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_k \text{megaregion dummy} + \varepsilon \quad (4.1)$$

Panel model

$$Y_{it}=\beta_0+\beta_k \text{accroad}_{\text{lag}}+\beta_k \text{accroad}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accroad}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{accrail}_{\text{lag}}+\beta_k \text{accrail}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accrail}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{period}_{9000}+\beta_k \text{period}_{0010}+\varepsilon_{it} \quad (4.2)$$

Multi-Level Model

$$Y_{ij}=\beta_{0j} + \beta_{1j} desln_{lag} + \beta_{2j} accroad_{lag} + \beta_{3j} \text{accrail}_{\text{lag}} + \beta_{kj} \text{megaregion dummy} + \varepsilon_{ij} \quad (4.3)$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

Y_{ij} is the outcome variable Y for local county i nested in megaregion j.

Spatial Error Model

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_4 \text{megaregion dummy} + \beta_5 \text{LAMDA} + \varepsilon \quad (4.4)$$

2. By **center class**: differentiated effects of road and rail transport accessibility between center areas and non-center areas. Counties are classified as megaregional centers or non-center areas based on the initial status of the county at the base year.

OLS

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_4 \text{center}_{\text{lag}}\#\text{accroad}_{\text{lag}} + \beta_5 \text{center}_{\text{lag}}\#\text{accrail}_{\text{lag}} + \beta_k \text{megaregion dummy} + \varepsilon \quad (4.5)$$

Panel model

$$Y_{it}=\beta_0+\beta_k \text{accroad}_{\text{lag}}+\beta_k \text{accroad}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accroad}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{accrail}_{\text{lag}}+\beta_k \text{accrail}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accrail}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{center}_{\text{lag}}+\beta_k \text{accroad}_{\text{lag}}\#\text{center}_{\text{lag}}+ \beta_k \text{accroad}_{\text{lag}}\#\text{center}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accroad}_{\text{lag}}\#\text{center}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{accrail}_{\text{lag}}\#\text{center}_{\text{lag}}+ \beta_k \text{accrail}_{\text{lag}}\#\text{center}_{\text{lag}}\#\text{period}_{9000}+ \beta_k \text{accrail}_{\text{lag}}\#\text{center}_{\text{lag}}\#\text{period}_{0010}+\beta_k \text{period}_{9000}+\beta_k \text{period}_{0010}+\varepsilon_{it} \quad (4.6)$$

Multi-Level Model

$$Y_{ij} = \beta_{0j} + \beta_{1j} \text{desln}_{\text{lag}} + \beta_{2j} \text{accroad}_{\text{lag}} + \beta_{3j} \text{accrail}_{\text{lag}} + \beta_{4j} \text{center}_{\text{lag}}\#\text{accroad}_{\text{lag}} + \beta_{5j} \text{center}_{\text{lag}}\#\text{accrail}_{\text{lag}} + \beta_{kj} \text{megaregion dummy} + \varepsilon_{ij} \quad (4.7)$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

Y_{ij} is the outcome variable Y for local county i nested in megaregion j.

Spatial Error Model

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_4 \text{center}_{\text{lag}}\#\text{accroad}_{\text{lag}} + \beta_5 \text{center}_{\text{lag}}\#\text{accrail}_{\text{lag}} + \beta_4 \text{megaregion dummy} + \beta_5 \text{LAMDA} + \varepsilon \quad (4.8)$$

3. By **coastal**: differential effects of transportation infrastructure on urban growth between coastal areas and inland areas. Counties are classified by location of the megaregion (whether it is located along the coast or not).

OLS

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_4\, cosatal + \beta_5 \text{coastal}\#\text{accroad}_{\text{lag}} + \beta_6 \text{coastal}\#\text{accrail}_{\text{lag}} + \beta_k \text{megaregion dummy} + \varepsilon \quad (4.9)$$

Panel model

$$Y_{it}=\beta_0 + \beta_k \text{accroad}_{\text{lag}} + \beta_k \text{accroad}_{\text{lag}}\#\text{period}_{9000} + \beta_k \text{accroad}_{\text{lag}}\#\text{period}_{0010} + \beta_k \text{accrail}_{\text{lag}} + \beta_k \text{accrail}_{\text{lag}}\#\text{period}_{9000} + \beta_k \text{accrail}_{\text{lag}}\#\text{period}_{0010} + \beta_k \text{Coastal} + \beta_k \text{accroad}_{\text{lag}}\#\text{coastal} + \beta_k \text{accroad}_{\text{lag}}\#\text{coastal}\#\text{period}_{9000} + \beta_k \text{accroad}_{\text{lag}}\#\text{coastal}\#\text{period}_{0010} + \beta_k \text{accrail}_{\text{lag}}\#\text{coastal} + \beta_k \text{accrail}_{\text{lag}}\#\text{coastal}\#\text{period}_{9000} + \beta_k \text{accrail}_{\text{lag}}\#\text{coastal}\#\text{period}_{0010} + \beta_k \text{period}_{9000} + \beta_k \text{period}_{0010} + \varepsilon_{it} \quad (4.10)$$

Multi-Level

$$Y_{ij}=\beta_{0j} + \beta_{1j} \text{desln}_{\text{lag}} + \beta_{2j} \text{accroad}_{\text{lag}} + \beta_{3j} \text{accrail}_{\text{lag}} + \beta_{4j}\, cosatal + \beta_{5j} \text{coastal}\#\text{accroad}_{\text{lag}} + \beta_{6j} \text{coastal}\#\text{accrail}_{\text{lag}} + \beta_{kj} \text{megaregion dummy} + \varepsilon_{ij} \quad (4.11)$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

Model Y_{ij} is the outcome variable Y for local county i nested in megaregion j.

Spatial Error Model

$$Y=\beta_0 + \beta_1 \text{desln}_{\text{lag}} + \beta_2 \text{accroad}_{\text{lag}} + \beta_3 \text{accrail}_{\text{lag}} + \beta_4\, cosatal + \beta_5 \text{coastal\#accroad}_{\text{lag}} + \beta_6 \text{coastal\#accrail}_{\text{lag}} + \beta_7 \text{megaregion dummy} + \beta_8 \text{LAMDA} + \varepsilon \quad (4.12)$$

The results from Multi-level models and spatial regression models are generally consistent with the results of OLS and Panel regression models. This research will mainly interpret the results from Panel regression and OLS models to analyze the effects of road and railway infrastructure, and make conclusions.

Table 4-14 Description of variables

Variables	Description
Dependent variable:	Key indicators of regional growth
desln	County-level population density in 1990, 2000 and 2010 (natural log)
poprate_ln	Annual population growth rate from 1982 to 1990; 1990 to 2000 and 2000 to 2010 (natural log)
Primary Explanatory Variables	
accroad_lag	Accessibility by road in the base year (1982, 1990, and 2000);
accroad_lag_9000(or 0010)	The interaction term between accessibility by road in base year and period 1990-2000 (or 2000-2010)
accrail_lag	Accessibility by rail in the base year (1982, 1990, and 2000)
accrail_lag_9000(or 0010)	The interaction term between accessibility by rail in base year and period 1990-2000 (or 2000-2010)
Control Variables	
Regional control variable	
Megaregion dummy variables	One dummy variable for each magaregion to control for regional fators, including weather and regional policy differentiations. Capital, Chuanyu, Guanzhong, Haixia, Liaoning, Pearl, Shandong, Wuhan, Yangtze, Zhongyuan.
coastal	1=this megaregion is along the East coast of China
County-level control variable	
desln_lag	County-level population density in the previous census year (1982, 1990 and 2000)
Center_lag	1=this county is classified as a major center in its megaregion in the base year (1982, 1990, and 2000)
Interaction control variables	
By center	
accroad_lag# center_lag	The interaction between county's accessibility by road in the base year and whether it is classified as a center in the base year
accrail_lag# center_lag	The interaction between county's accessibility by rail in the base year and whether it is classified as a center in the base year
accroad_lag# center_lag#period9000 (or 0010)	The interaction between county's accessibility by road in the base year and whether it is classified as a center in the base year and period 1990-2000 (or 2000-2010)
accrail_lag# center_lag#period9000 (or 0010)	The interaction between county's accessibility by rail in the base year and whether it is classified as a center in the base year and period 1990-2000 (or 2000-2010)
By coastal	
accroad_lag#coastal	The interaction between county's accessibility by road in the base year and whether it is located in the coastal area

Table 4-14 Description of variables (continued)

accrail_lag#coastal	The interaction between county's accessibility by rail in the base year and whether it is located in the coastal area
accroad_lag#coastal#period9000 (or 0010)	The interaction between county's accessibility by road in the base year and whether it is located in the coastal area and period 1990-2000 (or 2000-2010)
accrail_lag#coastal#period9000 (or 0010)	The interaction between county's accessibility by rail in the base year and whether it is located in the coastal area and period 1990-2000 (or 2000-2010)

*Pearson Correlation accroad_lag and accrail_lag is below 0.5 (0.49), so it will not cause multicollinearity problem for the regression.

The mean value and the standard deviation of the key variables are summarized below (Table 4-15):

Table 4-15 Mean and standard deviation of key variables

Variable	**Mean**	**Std.**
des	2816.961	16201.89
desln	6.510489	1.315763
poprateln	-0.98892	0.217812
accroad	24.21101	33.43703
accrail	22.23428	19.88995

4.6.1. The effects of transport infrastructure on population density

This part looks at the effects of transport infrastructure for **population density**. It is divided into three sets of models: general model, model by center and model by coastal location.

Table 4-16 Panel regression results for population density

desln	**General**		**By center**		**By coastal**	
VARIABLES	coef	pval	coef	pval	coef	pval
desln_lag	0.904***	0.000	0.817***	0.000	0.957***	0.000
accroad_lag	-0.00523***	0.000	0.0888***	0.000	-0.00920***	0.000
accroad_lag_9000	0.00635***	0.000	-0.0877***	0.000	0.0107***	0.000
accroad_lag_0010	0.00361**	0.017	-0.0811***	0.000	0.00975***	0.003
accrail_lag	0.0245***	0.000	-0.0350	0.120	0.00760	0.168
accrail_lag_9000	0.0338***	0.000	0.0942***	0.000	0.0182***	0.002
accrail_lag_0010	-0.00995**	0.025	0.0486**	0.035	-0.00426	0.484
center_lag			0.544***	0.000		
accroad_lag_center			-0.0929***	0.000		
accroad_lag_center_9000			0.0950***	0.000		
accroad_lag_center_0010			0.0837***	0.000		
accrail_lag_center			0.0461**	0.040		
accrail_lag_center_9000			-0.0552**	0.020		
accrail_lag_center_0010			-0.0468**	0.042		
period9000	-0.503***	0.000	-0.244***	0.000	-0.453***	0.000
period0010	-0.0961*	0.081	0.0648	0.283	-0.215***	0.000
capital	-0.181***	0.000	-0.258***	0.000		
chuanyu	-0.353***	0.000	-0.448***	0.000		
guanzhong	0.0788	0.180	0.0702	0.223		
haixia	0.201***	0.001	0.178***	0.002		
liaoning	0.0578	0.293	-0.00135	0.980		
pearl	0.0596	0.297	0.0397	0.477		
shandong	0.0451	0.426	0.0720	0.192		
wuhan	-0.132***	0.010	-0.139***	0.005		
yangtze	-0.214***	0.000	-0.210***	0.000		
coastal					0.00280	0.954
accroadlag_coastal					0.00933***	0.001
accroadlag_coastal_9000					0.00515	0.506
accroadlag_coastal_0010					-0.0112***	0.004
accraillag_coastal					-0.0123**	0.038
accraillag_coastal_9000					0.0170*	0.065
accraillag_coastal_0010					0.0178***	0.003
Constant	0.619***	0.000	0.813***	0.000	0.424***	0.000
Observations	3,006		3,006		3,006	
Number of centroid	1,004		1,004		1,004	
df_m	18		25		16	
chi2	13569		14563		13207	

A. General model

The General model (Table 4-16) assesses the differentiated effects of accessibility by road and rail infrastructure. The railway lag variable is positively significant in all the three time periods. This implies that railway endowment and the change of accessibility level by railway have positive effects on regional growth measured by population density. The road lag variable is negatively significant during the 1982-1990 and 2000-2010 periods, and positively significant during 1990-2000 period. It should also be noted that the coefficient for railway accessibility is larger than that for road accessibility.

The results from OLS model (Table C-1) assessing the differentiated effects of accessibility by road and rail infrastructure are generally consistent with the panel model results. The rail lag variable is positively significant during all the three time periods, while the positive effects dropped during the 2000-2010 periods. The road accessibility variable has similar results in OLS models: the road lag variable is negatively during the period 1982-1990 (one-tail 0.1 level), positively significant during 1990-2000, and negatively significant during the 2000-2010 period. This indicates that only during the 1990-2000 period, road endowment and improvement lead to higher population densities while holding other variables constant.

These results confirm the research hypothesis that for all the counties in the ten megaregions in general, the growth impacts (measured by population density) of railway accessibility is stronger than road accessibility especially during the two early periods: 1982-1990 and 1990-2000. This trend became less strong during the 2000-2010 periods, with the effects of railway endowment dropped.

B. By center model

The panel regression results (Table 4-16) indicate that: during the 1982-1990 period, road has stronger positive effects for non-center areas, and rail has stronger positive effects for center areas; during the two periods after 1990, railway effects are stronger for both center and non-center areas.

In the OLS model (Table C-2), the road lag variable for non-central areas is positively significant during the first two periods, which means that road accessibility has positive impacts for population density in areas classified as non-centers. For center areas, road lag variable is only negatively significant in the 1982-1990 period. The rail lag variable is negatively significant during the 1982-1990 period for non-center areas, positively significant during the 1990-2000 period, and positive but not sigfinicant during the 2000-2010 period. The rail lag variable is positively significant for non-center areas during 1990-2000, and not significant during the 1982-1990 and 2000-2010 periods. For center areas, railway is positively significant during 1982-1990. For the other two periods after 1990, the interaction term accrail#center is negative (not significant), but the net effects are still positive.

As for the results of railway accessibility, the two models are in general consistent with each other. In conclusion, the model results suggest that that railway accessibility have stronger positive impacts for both center and non-center areas in terms of population density after 1990.

C. By coastal model

The panel regression model (Table 4-16) model indicates that during the two periods after 1990 railway has stronger positive effects than roadway for both coastal and inland areas, and railway's effects are stronger in coastal areas than in inland areas.

Railway has significant positive impacts in inland areas during all the three periods, 1982-1990 (one-tail 0.1 level), 1990-2000 and 2000-2010. For inland areas, road accessibility is negatively significant during the first period 1982-1990, and positively significant during the two periods 1990-2000 and 2000-2010.

The OLS model results (Table C-3) are in general consistent with the panel results.

4.6.2. The effects of transport infrastructure on population growth rates

This part looks at the effects of transport infrastructure for population growth rate. It is divided into three sets of models: general model, model by center and model by coastal location. Each set will compare the results from panel regression and OLS models. The results of MLM models and spatial regression models are listed in the Appendix.

Table 4-17 Panel regression results for population growth rate

popraten	**General**		**By center**		**By coastal**	
VARIABLES	coef	pval	coef	pval	coef	pval
desln_lag	-0.0460***	0.000	-0.0734***	0.000	-0.0294***	0.000
accroad_lag	-0.00330***	0.000	0.0265***	0.000	-0.00621***	0.000
accroad_lag_9000	0.00353***	0.000	-0.0263***	0.000	0.00653***	0.000
accroad_lag_0010	0.00293***	0.000	-0.0240***	0.002	0.00641***	0.000
accrail_lag	0.00886***	0.000	-0.00921	0.246	0.00506***	0.008
accrail_lag_9000	0.00653***	0.000	0.0262***	0.001	0.000959	0.639
accrail_lag_0010	-0.00391**	0.012	0.0129	0.112	-0.00336	0.112
center_lag			0.173***	0.000		
accroad_lag_center			-0.0294***	0.000		
accroad_lag_center_9000			0.0291***	0.000		
accroad_lag_center_0010			0.0266***	0.001		
accrail_lag_center			0.0136*	0.087		
accrail_lag_center_9000			-0.0170**	0.042		
accrail_lag_center_0010			-0.0129	0.113		
period9000	-0.133***	0.000	-0.0568**	0.012	-0.122***	0.000
period0010	-0.0332*	0.086	0.0367*	0.085	-0.0705***	0.000
capital	-0.0646***	0.000	-0.0888***	0.000		
chuanyu	-0.125***	0.000	-0.158***	0.000		
guanzhong	0.00721	0.727	0.00446	0.827		
haixia	0.0452**	0.032	0.0374*	0.071		
liaoning	0.000795	0.967	-0.0168	0.380		
pearl	-0.0265	0.186	-0.0347*	0.078		
shandong	-0.00655	0.741	-0.000195	0.992		
wuhan	-0.0601***	0.001	-0.0638***	0.000		
yangtze	-0.0630***	0.001	-0.0620***	0.001		
coastal					-0.00253	0.882
accroadlag_coastal					0.00643***	0.000
accroadlag_coastal_9000					-0.00230	0.394
accroadlag_coastal_0010					-0.00699***	0.000
accraillag_coastal					-0.00665***	0.001
accraillag_coastal_9000					0.00818**	0.011
accraillag_coastal_0010					0.00833***	0.000
Constant	-0.721***	0.000	-0.665***	0.000	-0.797***	0.000
Observations	3,006		3,006		3,006	
Number of centroid	1,004		1,004		1,004	
df_m	18		25		16	
chi2	360.5		526.8		340.8	

Y=ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

A. General model

The General model (Table 4-17) finds that rail lag variable is positively significant during all three periods, although the 2000-2010 effects is less than the previous two periods. Road lag variable is negatively significant during the first and third period 1982-1990 and 2000-2010.

The OLS model (Table C-4) finds similar results. Road lag variable is only positively significant during the 1990-2000 periods. Therefore, the two models confirm that railway has stronger positive effects for regional growth measured by population growth rate, however this trend became less stronger during the 2000-2010 periods.

B. By center model

In the panel model (Table 4-17), road accessibility is positively significant for non-center areas during all the three periods. Railway accessibility is positively significant during the two periods after 1990. The coefficients of railway accessibility is greater that of roadway accessibility. For center areas, road accessibility is negatively significant during all three periods. Rail is positive during all three periods.

Therefore the model suggests that: in terms population growth rates after 1990, railway has stronger positive impacts for both center and non-center areas.

The results of the OLS model (Table C-5) has similar results, but the interaction terms between center and road/railway accessibility are mostly not significant, so it is difficult to generate any consistent trend from the OLS model for center areas.

C. By coastal model

In the panel model (Table 4-17), for inland areas, road accessibility is negatively significant during the first period 1982-1990, and after that road accessibility is positively significant for inland areas. The railway effects for inland areas are positively significant during the first periods, and are positive but not significant during the 1990-2000 and 2000-2010 periods. The railway effects for coastal areas are positively significant during the last two decades, while the road effects for coastal areas become negative after 2000.

The results of the OLS model (Table C-6) are generally consistent with the panel model results. However there are differences. In the OLS model the 1982-1990 period, the road#coastal interaction term is positive (not significant) during the 1990-2000 period, which is negative (not significant) in the panel model.

Therefore, these results indicate that railway infrastructure has stronger positive effects for both coastal and inland areas during the three periods in terms of population growth rate.

4.6.3. Model conclusions

As shown above, several regression models were run, using different sets of variables and using different regression methods. The results from panel regression, OLS, Multi-Level Model and spatial regression models are generally consistent with each other. The effects are not necessarily positive for all the regions. The effect can also change during different time periods. Some of the regions maybe negatively influenced.

General statement

The results confirm the research hypothesis that in general railway has stronger positive impacts for regional growth compared with roadway, especially in the early two periods, and this applies to the two measures by population density and population growth rate. This trend became less strong during the 2000-2010 periods, with the effects of railway dropped.

Differentiation between center areas and non-center areas:

In the two periods after 1990 rail accessibility has stronger positive impacts for both center and non-center areas measured by population density and population growth rate.

Differentiation between coastal areas and non-coastal areas:

Consistent trend shows in the two periods after 1990: railway has stronger positive effects than roadway for both coastal and inland areas, and railway's effects are stronger in coastal areas than in inland areas. This applies to the two measures by population density and population growth rate.

CHAPTER 5. CONCLUSIONS AND POLICY IMPLICATIONS

5.1. Conclusions

Understanding the spatial patterns of China's megaregions and the impacts of transport infrastructure for the formation and evolution of megaregional spatial patterns is the ultimate objective of this dissertation. This research examines the spatial patterns, transport network and the relationship between transport network and spatial patterns for the ten megaregions in China at two scale levels: the megaregional level and the local level.

Spatial pattern

The classic urban and regional theories maintain its strength in understanding the sizes and numbers of places, the relationship between functions of places and their ranks in urban hierarchy, and the spatial pattern of urban networks. This research tries to provide a quantitative measure for the spatial pattern under the emerging trend of megaregions globally.

The empirical evidence confirms the first research hypothesis: the spatial demographic patterns of China's megaregions vary significantly in polycentricity, and the evolution of megaregions' polycentricity is not a unidirectional progress. To elaborate, during the 1982-1990 period, the polycentricity indexes for nine of the ten megaregions increased; this increasing trend became less significant during the 1990-2000 period, with five megaregions showing increases or having the same level of their polycentricity indexes;

during the 2000-2010 period, eight megaregions either show polycentricity increases or stay at the same level. Despite the fluctuations of polycentricity index during the three time periods, all the ten megaregions have steadily become more polycentric during the whole study period.

In addition, a One-way ANOVA test of megaregional polycentricity by coastal reveals that coastal megaregions are more polycentric than inland megaregions. This dissertation also calculates a set of alternative measures of regional spatial pattern, and concludes that the polycentricity index is more appropriate for analyzing the spatial pattern of megaregions. At the local level, the spatial statistics analyses of the spatial pattern of population density and population growth rate prove that high density and high growth areas tend to cluster together.

Transport network

The most striking aspect of transport network is that the growth rates of network densities accelerated during the 2000-2010 periods. This trend is more significant for railway network, due to the large-scale construction of high-speed rail network. Railway network density growths are more significant in the coastal megaregions, and this is due to the fact that large share of the new high-speed railways are constructed in the coastal areas. Road network densities in inland megaregions are generally lower than the coastal megaregions.

In terms of transport link length per capita, initially coastal areas have higher road length per capita, while inland areas have higher rail length per capita. The trends were shifted

during the 2000-2010 period, during which coastal and inland areas have almost equal endowment of road and rail transport infrastructure by link length per capita.

The local level analysis of transport network looks at the changes of connectivity and accessibility for local counties. For both connectivity and accessibility, the most significant change occurs between 2000 and 2010. Coastal and inland megaregions have all benefited significantly from the transport improvement in terms of connectivity and accessibility in the past few decades.

The growth impacts of transport infrastructure

The literature review has summarized a series of research and studies that found striking variances of the beneficial effects of transport infrastructure across regions and across different periods. This study examined the differentiated effects of transport infrastructure comprehensively for China's 10 megaregions using the most updated data. The results confirm the research hypothesis that in general railway has stronger positive impacts for regional growth compared with roadway, especially in the early two periods, and this applies to the two measures by population density and population growth rate. Rail accessibility has stronger positive impacts for center areas measured by **population density**. The research also finds that the impacts for rail infrastructure are stronger for the inland areas before 2000. The models for **population growth rates** indicate similar results that railway infrastructure has stronger positive effects for inland areas during the three periods in terms of population growth rate. There is no clear differentiation pattern for road accessibility between center and non-center areas or between coastal and inland areas.

The stronger effects of railway for center areas have been diminished during the 2000-2010 period and the differentiated effects of road and rail for center and non-center areas became less significant. Because this research looks at transport network at the megaregions level, the division between center and non-center areas is less meaningful than the differentiation between coastal and inland areas.

In the most recent period 2000-2010, the effects of road for inland areas are stronger than the coastal areas, while there are no significant differentiating effects for railway between coastal and inland areas. Despite the complex differentiation effects, the magnitude of the effects of railway is always stronger than that of the roadway. Therefore, based on these research results, this dissertation recommends a priority shift of transport priorities to rail infrastructure in the inland areas.

5.2. Policy implications

In the 1960's the US government embarked on highway construction and rehabilitation initiatives to develop the lagging and rural intra-state regions of the nation. Results have shown the beneficial effects of new interstate highways for small cities; however, it took nearly two decades for the rural areas and off-freeway counties to experience substantial growth following the interstate highway construction (Rephann & Isserman, 1994). It appears that we are witnessing a similar phenomenon in China today.

A highly polycentric interurban spatial pattern at the megaregional level matters not only from the morphological perspective, but also from the economic and functional perspectives. Megaregions are integrated sets of cities and their surrounding suburban

hinterlands across which labor and capital can be reallocated at relatively low cost. Administrative and political boundaries became less important in economic terms. The continuously fading political barriers have tremendous economic implications for economic interaction (Baldwin & Venables, 1995).

In China, the vertical and horizontal linkages across regions are not well established; functional integration at the megaregional level is still inadequate; and there is a policy vacuum over cross-border issues and a lack of a national vision. A spatially polycentric and balanced geographic pattern is the prerequisite to achieve an economically competitive and environmentally sustainable development trajectory. A megaregional approach to planning has been identified as one of the key instruments to promote a more balanced regional and national development pattern in China.

What should be emphasized here is the role of transportation investment to redefine the relative advantage of each part within a megaregion as higher mobility can play a significant role in influencing the spatial pattern of urban spaces and further enhancing the polycentric spatial pattern (Song & Yang, 2011). In China, high speed railways, highway, airports and other traditional transportation modes have been used to establish greater links between cities within megaregion and between megaregions.

Improved transportation infrastructure could bring development opportunities in some of the second-tier centers and help them grow into major centers. Some areas currently classified as non-centers may also grow into major or second-tier centers. Improved megaregional transportation infrastructure could contribute to a more balanced spatial

pattern of population and economic activities. For megaregions, the completion of megaregional transport systems will strengthen connections between cities of the region and cut travel costs between cities (J. Yang, Ross, et al., 2011)..

The key challenge is to explore and identify the potential instruments to promote a more polycentric megaregional spatial pattern and truly balanced regional competitiveness. The linkages of transportation investment and urban development have long been recognized. This research tries to examine in what way and to what extent transportation investments have impacted on the formation and evolution of megaregional spatial pattern. The research results confirm the stronger positive effects of railway for regional growth. However most of the recent railway projects are in the coastal areas. Therefore, based on these research results, this dissertation recommends a priority shift of transport priorities to rail infrastructure in the inland areas.

This research aims to understand and model the dynamics of megaregional spatial pattern, by looking into multi-year spatial pattern shift from 1980's that allows us to single out the impacts of transportation investment. As mentioned before, at the beginning of the 21 century, China's megaregions have entered their initial stages of development. Therefore, deeper understanding of the implications of transportation investments for the formation and growth of megaregional spatial pattern will inform future planning actions.

The planning system in China has been moving toward the decentralization of decision making, market-led development, and the state and centrally-planned economy have less

significant role in influencing the development of cities and regions (Yeh & Wu, 1999). However despite the recent shifts in planning and decision-making processes, the state is still 'ultimately involved in regulating the market and thus determining the final spatial outcomes'(Madrazo & van Kempen, 2012). To some extent, this offers opportunities for grand, long-term actions to happen, given that the period of a political position is often limited and short term, especially for the political positions at or below provincial level. One possible instrument is the controversial Hukou system (household registration system), which can nevertheless to some extent provides some control of the excessive concentration in the major cities. The Hukou system has been enforced more strictly in the megacities like Beijing and Shanghai. This provides some opportunities for second-tier cities to grow and develop.

Governments at different levels are making wide-ranging, comprehensive changes under the direction and facilitation of central government. These changes imply the coordination of a mixture of different policy sectors and the collaboration between jurisdictions. Considering the rapid population growth, economic development and global changes happening to China, the responsibility of planning authorities to provide an efficiently functioning transportation network which can also help achieving a more balanced development pattern, is truly challenging. It calls for a broader and longer-term approach than the previous town planning systems, to strategically manage spaces and organize resources with a wider regard for a balanced development pattern among regions.

5.3. Future research

Transport infrastructure is not entirely exogenous because it is supplied by governments that respond to changes in needs which are generated by economic growth, and therefore infrastructure can be both a cause and a consequence of economic growth (Rietveld, 1994, p. 332). This research uses Granger-causality approach by adding lagged independent variables to explore the causal relationship between transport infrastructure and local growth. However, as identified in literature review, regional growth is influenced by a complex set of factors besides transport infrastructure. Some of the omitted factors are controlled by megaregional dummy variables, which can only partially control for some regional factors being omitted. Future research should include more data and utilize more advanced statistics methods.

The literature review part mentioned a recent research by Duranton and Turner (Duranton & Turner, 2012). Their study uses a 1947 plan of the interstate highway system, an 1898 map of railroads, and maps of the early explorations of the U.S. as instruments for 1983 highways. Therefore, one direction in future research is to find suitable instruments that can predicts the initial level of road in 1982 and affect the growth of local population only their effect on the initial stock of transport infrastructure, so that an instrumental variables estimation can be implemented. As suggested by Duranton and Turner (p. 1408), possible instruments should either reflect the level of transport infrastructure long time ago or the suitability of its geography for constructing transport infrastructure.

APPENDIX A.

STATISTICS OF ALTERNATIVE MEASURES OF POLYCENTRICITY

Table A-1 Number of centers per million population

	1982	1990	2000	2010	% change (1982-2010)
Capital Economic Zone	10.4	12.8	8.1	8.0	-23%
ChuanYu MegaRegion	4.6	5.5	4.3	5.5	19%
GuanZhong MegaRegion	7.8	9.4	5.9	6.5	-17%
HaiXia West MegaRegion	16.1	13.7	8.2	6.7	-59%
LiaoNing MegaRegion	13.5	15.6	7.4	5.1	-63%
Pearl River Delta	9.0	8.5	10.5	7.7	-14%
ShanDong MegaRegion	1.0	3.6	2.9	2.7	163%
Wuhan MegaRegion	3.1	4.9	3.5	3.7	19%
Yangtze River Delta	2.5	2.6	2.3	2.2	-10%
ZhongYuan MegaRegion	3.8	3.9	2.6	2.5	-35%

Table A-2 Number of centers per thousand sq km

	1982	1990	2000	2010	%change (1982-2010)
Capital Economic Zone	3.1	4.5	3.1	3.5	12%
ChuanYu MegaRegion	1.6	2.1	1.7	2.1	28%
GuanZhong MegaRegion	2.4	3.3	2.3	2.7	15%
HaiXia West MegaRegion	5.4	5.4	3.8	3.6	-33%
LiaoNing MegaRegion	3.7	4.8	2.4	1.8	-52%
Pearl River Delta	3.2	3.6	7.2	6.9	117%
ShanDong MegaRegion	0.5	1.8	1.6	1.5	230%
Wuhan MegaRegion	1.0	1.8	1.4	1.4	38%
Yangtze River Delta	1.6	1.8	1.9	2.4	45%
ZhongYuan MegaRegion	1.9	2.3	1.7	1.7	-8%

Table A-3 Population served per center

	1982	1990	2000	2010	%change (1982-2010)
Capital Economic Zone	96536	77979	124091	125720	30%
ChuanYu MegaRegion	218166	180705	232486	182739	-16%
GuanZhong MegaRegion	127989	105967	169477	154781	21%
HaiXia West MegaRegion	61973	72946	121247	150293	143%
LiaoNing MegaRegion	73808	64128	135863	197556	168%
Pearl River Delta	110675	117897	95260	129108	17%
ShanDong MegaRegion	990886	276459	344108	376926	-62%
Wuhan MegaRegion	318690	204131	288368	268336	-16%
Yangtze River Delta	404524	382204	435882	451685	12%
ZhongYuan MegaRegion	265253	253571	386889	406482	53%

Table A-4 Average center size by population

	1982	1990	2000	2010	% change (1982-2010)
Capital Economic Zone	32396	29831	48003	53557	65%
ChuanYu MegaRegion	26693	30901	37610	41093	54%
GuanZhong MegaRegion	30287	31310	48550	53248	76%
HaiXia West MegaRegion	18526	22360	39686	52917	186%
LiaoNing MegaRegion	26241	27508	55483	74127	182%
Pearl River Delta	42394	46976	63667	82507	95%
ShanDong MegaRegion	97788	30742	59790	74662	-24%
Wuhan MegaRegion	35023	29275	46460	50562	44%
Yangtze River Delta	80115	80778	131094	165636	107%
ZhongYuan MegaRegion	36451	42501	72577	95938	163%

APPENDIX B.

REGRESSION RESULTS OF MODELS ASSESSING THE IMPACTS OF MEGA-REGIONAL TRANSPORT INFRASTRUCTURE FOR ALTERNATIVE POLYCENTRICITY MEASURES

Table B-1 Number of centers per million population and megaregional transport network

	(1)		(2)		(3)	
VARIABLES	coef	pval	coef	pval	coef	pval
center_permill_pop_lag	0.561***	0.000	0.591***	0.000	0.560***	0.001
coastal	1.076	0.369	0.704	0.580	0.682	0.510
megapopdes	-0.00229	0.466	-0.00387	0.247	-0.00400	0.218
roaddes_lag	-0.0263	0.484				
raildes_lag	-0.00734	0.912				
roadcap_lag			-0.000860	0.961		
railcap_lag			-0.00682	0.803		
road_ellip_lag					0	0.712
rail_ellip_lag					-0	0.629
Constant	4.777**	0.035	4.093	0.217	4.115	0.147
Observations	30		30		30	
R-squared	0.705		0.693		0.694	

Y: center_permill_pop *** p<0.01, ** p<0.05, * p<0.1

Table B-2 Number of centers per sq. km and megaregional transport network

	(1)		(2)		(3)	
VARIABLES	coef	pval	coef	pval	coef	pval
center_permill_pop_lag						
coastal	0.000574	0.285	0.000358	0.549	0.000342	0.473
megapopdes	1.61e-06	0.260	2.65e-07	0.853	4.01e-07	0.742
roaddes_lag	-1.76e-05	0.331				
raildes_lag	-7.69e-06	0.811				
roadcap_lag			-3.65e-07	0.967		
railcap_lag			-6.38e-06	0.639		
road_ellip_lag					0	0.723
rail_ellip_lag					-0	0.545
center_perkm_lag	0.689***	0.000	0.728***	0.000	0.673***	0.001
pop_per_center_lag						
avg_center_pop_lag						
Constant	0.00115	0.193	0.000843	0.577	0.000812	0.466
Observations	30		30		30	
R-squared	0.640		0.610		0.610	

Y: center_perkm *** p<0.01, ** p<0.05, * p<0.1

Table B-3 Population per center and megaregional transport network

	(1)		(2)		(3)	
VARIABLES	coef	pval	coef	pval	coef	pval
center_permill_pop_lag						
coastal	-63,024*	0.078	-54,981	0.172	-50,135*	0.088
megapopdes	320.0***	0.005	360.9***	0.002	400.8***	0.000
roaddes_lag	372.3	0.771				
raildes_lag	2,089	0.368				
roadcap_lag			-209.2	0.737		
railcap_lag			833.8	0.387		
road_ellip_lag					-1.56e-06	0.164
rail_ellip_lag					2.79e-06**	0.046
center_perkm_lag						
pop_per_center_lag	0.272***	0.003	0.282***	0.002	0.228***	0.009
avg_center_pop_lag						
Constant	-30,678	0.564	1,629	0.988	-33,502	0.558
Observations	30		30		30	
R-squared	0.680		0.660		0.706	

Y: pop_per_center *** p<0.01, ** p<0.05, * p<0.1

Table B-4 Average population of megaregional center and megaregional transport network

	(1)		**(2)**		**(3)**	
VARIABLES	coef	pval	coef	pval	coef	pval
coastal	709.7	0.917	-4,397	0.555	3,833	0.539
megapopdes	114.6***	0.000	153.4***	0.000	128.0***	0.000
roaddes_lag	121.0	0.646				
raildes_lag	769.8	0.102				
roadcap_lag			104.2	0.386		
railcap_lag			279.3	0.132		
road_ellip_lag					-4.74e-07*	0.062
rail_ellip_lag					6.60e-07**	0.040
avg_center_pop_lag	0.197	0.315	0.195	0.292	0.210	0.298
Constant	-32,294***	0.009	-55,619**	0.013	-20,357	0.118
Observations	30		30		30	
R-squared	0.819		0.828		0.807	

Y: avg_center_pop *** p<0.01, ** p<0.05, * p<0.1

APPENDIX C.

OLS MODEL RESULTS

Table C-1 OLS General model for ln(population density)

	1990		**2000**		**2010**	
desln	coef	pval	coef	pval	coef	pval
desln_lag	0.732***	0.000	0.824***	0.000	1.029***	0.000
accroad_lag	-0.00462	0.122	0.000892***	0.000	-0.00128***	0.006
accrail_lag	0.0398***	0.000	0.0875***	0.000	0.00306**	0.049
capital	-0.246***	0.000	-0.436***	0.000	0.0195	0.527
chuanyu	-0.421***	0.000	-0.818***	0.000	-0.102***	0.000
guanzhong	-0.0936*	0.072	0.339***	0.007	0.00537	0.850
haixia	0.0225	0.663	0.580***	0.000	0.0192	0.726
liaoning	-0.0670	0.269	0.183	0.267	-0.0507*	0.078
pearl	-0.188*	0.074	0.261**	0.011	0.0672*	0.066
shandong	-0.105	0.207	0.208*	0.068	-0.00509	0.868
wuhan	-0.184**	0.013	-0.193*	0.069	-0.118***	0.000
yangtze	-0.284***	0.000	-0.618***	0.000	0.0754*	0.064
Constant	1.614***	0.000	0.316	0.258	-0.149**	0.013
Observations	1,001		1,004		1,001	
R-squared	0.750		0.719		0.975	
ll	-753.3		-1177		-28.12	
df_m	12		12		12	
Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1						

Table C-2 OLS: ln(population density) by center

	1990		**2000**		**2010**	
desln	coef	pval	coef	pval	coef	pval
desln_lag	0.650***	0.000	0.630***	0.000	1.002***	0.000
accroad_lag	0.0895***	0.001	0.000723***	0.000	0.00295	0.523
accrail_lag	-0.0281	0.282	0.0920***	0.000	0.00373	0.443
center_lag	0.749***	0.000	0.647***	0.003	0.205***	0.000
1.center_lag#c.accroad_lag	-0.0936***	0.000	-0.00115	0.954	-0.00421	0.363
1.center_lag#c.accrail_lag	0.0497*	0.051	-0.00627	0.792	-0.00109	0.829
capital	-0.336***	0.000	-0.520***	0.000	-0.0234	0.459
chuanyu	-0.561***	0.000	-0.873***	0.000	-0.141***	0.000
guanzhong	-0.0757	0.164	0.253**	0.044	0.0125	0.642
haixia	0.00845	0.842	0.488***	0.000	0.0191	0.729
liaoning	-0.112*	0.081	0.0351	0.828	-0.0704**	0.023
pearl	-0.206**	0.041	0.255**	0.015	0.0388	0.286
shandong	-0.0195	0.811	0.251**	0.022	0.000176	0.995
wuhan	-0.173**	0.018	-0.203**	0.050	-0.123***	0.000
yangtze	-0.230***	0.000	-0.554***	0.000	0.0365	0.399
Constant	1.797***	0.000	1.368***	0.000	-0.0656	0.432
Observations	1,001		1,004		1,001	
R-squared	0.768		0.729		0.975	
ll	-716.3		-1159		-15.96	
df_m	15		15		15	

Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table C-3 OLS: ln(population density) by coastal

	1990		**2000**		**2010**	
desln	coef	pval	coef	pval	coef	pval
desln_lag	0.797***	0.000	0.981***	0.000	1.031***	0.000
accroad_lag	-0.00889***	0.000	0.00166***	0.000	0.000368	0.272
accrail_lag	0.0299***	0.001	0.0111	0.239	0.00193**	0.024
coastal	0.150*	0.077	-0.332**	0.019	0.0945***	0.002
1.coastal#c.accroad_lag	0.00955***	0.000	0.0127	0.501	-0.00181***	0.001
1.coastal#c.accrail_lag	-0.0200**	0.026	0.0253	0.267	0.00190	0.236
Constant	1.140***	0.000	0.0586	0.820	-0.244***	0.000
Observations	1,001		1,004		1,001	
R-squared	0.745		0.680		0.974	
ll	-763.6		-1242		-42.85	
df_m	6		6		6	

Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table C-4 OLS General model for ln(population growth rate)

	1990		**2000**		**2010**	
popratelnn	coef	pval	coef	pval	coef	pval
desln_lag	-0.136***	0.000	-0.0662***	0.000	0.00762***	0.005
accroad_lag	-0.00307	0.127	0.000177***	0.001	-0.000371***	0.009
accrail_lag	0.0198***	0.000	0.0224***	0.000	0.000818**	0.043
capital	-0.118***	0.000	-0.126***	0.000	0.00482	0.564
chuanyu	-0.227***	0.000	-0.234***	0.000	-0.0285***	0.000
guanzhong	-0.0485**	0.026	0.0678**	0.027	0.00125	0.869
haixia	0.000753	0.972	0.133***	0.000	0.00232	0.878
liaoning	-0.0405*	0.089	0.0172	0.680	-0.0138*	0.078
pearl	-0.164**	0.033	0.0517*	0.060	0.0185*	0.061
shandong	-0.0813**	0.025	0.0437	0.135	-0.00174	0.833
wuhan	-0.108***	0.000	-0.0811**	0.035	-0.0331***	0.000
yangtze	-0.121***	0.000	-0.159***	0.000	0.0178	0.113
Constant	-0.222	0.161	-0.801***	0.000	-1.059***	0.000
Observations	1,001		1,004		1,001	
R-squared	0.174		0.205		0.155	
ll	-53.80		125.8		1272	
df_m	12		12		12	

Y=ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table C-5 ln(population growth rate) by center

	1990		**2000**		**2010**	
popratelnn	coef	pval	coef	pval	coef	pval
desln_lag	-0.174***	0.000	-0.115***	0.000	7.62e-05	0.985
accroad_lag	0.0294***	0.000	0.000129***	0.002	0.000692	0.559
accrail_lag	-0.00316	0.721	0.0242***	0.000	0.00113	0.371
center_lag	0.295***	0.000	0.181***	0.002	0.0566***	0.000
1.center_lag#c.accroad_lag	-0.0323***	0.000	-0.000686	0.890	-0.00105	0.375
1.center_lag#c.accrail_lag	0.0166**	0.040	-0.00234	0.706	-0.000433	0.738
capital	-0.153***	0.000	-0.148***	0.000	-0.00700	0.418
chuanyu	-0.278***	0.000	-0.249***	0.000	-0.0389***	0.000
guanzhong	-0.0461**	0.038	0.0479	0.121	0.00347	0.632
haixia	-0.0105	0.551	0.111***	0.001	0.00255	0.868
liaoning	-0.0648**	0.014	-0.0189	0.648	-0.0191**	0.023
pearl	-0.174**	0.026	0.0491*	0.078	0.0108	0.273
shandong	-0.0465	0.182	0.0552**	0.050	-0.000116	0.988
wuhan	-0.105***	0.000	-0.0831**	0.028	-0.0343***	0.000
yangtze	-0.100***	0.002	-0.144***	0.000	0.00696	0.561
Constant	-0.103	0.596	-0.544***	0.000	-1.037***	0.000
Observations	1,001		1,004		1,001	
R-squared	0.207		0.229		0.176	
ll	-33.63		141.5		1284	
df_m	15		15		15	
chi2	.		.		.	
aic	.		.		.	

Y=ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table C-6 OLS: ln(population growth rate) by coastal

	1990		**2000**		**2010**	
popratelnn	coef	pval	coef	pval	coef	pval
desln_lag	-0.104***	0.000	-0.0241	0.129	0.00807***	0.001
accroad_lag	-0.00601***	0.000	0.000374***	0.000	0.000107	0.242
accrail_lag	0.0133***	0.001	0.00217	0.468	0.000526**	0.025
coastal	0.0246	0.486	-0.0924**	0.025	0.0267***	0.000
1.coastal#c.accroad_lag	0.00642***	0.000	0.00368	0.425	-0.000519***	0.001
1.coastal#c.accrail_lag	-0.00704*	0.084	0.00704	0.226	0.000476	0.245
Constant	-0.435***	0.001	-0.890***	0.000	-1.087***	0.000
Observations	1,001		1,004		1,001	
R-squared	0.159		0.114		0.131	
ll	-62.83		71.38		1257	
df_m	6		6		6	

Y=ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

APPENDIX D.

MLM MODEL RESULTS

Table D-1 MLM: ln(population density) general model

desln	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	0.751***	0.000	0.834***	0.000	1.029***	0.000
accroad_lag	-0.00453***	0.000	0.000925	0.187	-0.00129***	0.000
accrail_lag	0.0329***	0.000	0.0844***	0.000	0.00334***	0.000
Constant	1.397***	0.000	0.239	0.270	-0.165***	0.000
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-766.5		-1199		-41.69	
df_m	3		3		3	
chi2	2640		2209		34264	
Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1						

Table D-2 MLM: ln(population density) general model

desln	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	0.665***	0.000	0.639***	0.000	1.004***	0.000
accroad_lag	0.0876***	0.000	0.000756	0.275	0.00278	0.231
accrail_lag	-0.0317	0.138	0.0886***	0.000	0.00391	0.129
center_lag	0.718***	0.000	0.639***	0.000	0.200***	0.000
1.center_lag#c.accroad_lag	-0.0917***	0.000	-0.000689	0.943	-0.00404*	0.083
1.center_lag#c.accrail_lag	0.0500**	0.017	-0.00602	0.643	-0.00119	0.646
Constant	1.586***	0.000	1.262***	0.000	-0.104*	0.088
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-732.8		-1180		-29.74	
df_m	6		6		6	
chi2	2881		2330		35101	
Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1						

Table D-3 MLM: ln(population density) by coastal

desln	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	0.739***	0.000	0.855***	0.000	1.029***	0.000
accroad_lag	-0.00885***	0.000	0.00122*	0.082	0.000729	0.519
accrail_lag	0.0631***	0.000	0.0533***	0.000	0.00240	0.178
coastal	0.353***	0.004	-0.320	0.265	0.108**	0.011
1.coastal#c.accroad_lag	0.00938***	0.000	0.000323	0.974	-0.00211*	0.069
1.coastal#c.accrail_lag	-0.0430***	0.000	0.0394***	0.010	0.000761	0.687
Constant	1.212***	0.000	0.378	0.157	-0.229***	0.000
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-753.2		-1191		-37.08	
df_m	6		6		6	
chi2	2727		2258		34781	

Y=ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table D-4 MLM: ln(population growth rate) general model

poprateln	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	-0.128***	0.000	-0.0633***	0.000	0.00761***	0.000
accroad_lag	-0.00304***	0.000	0.000187	0.330	-0.000373***	0.000
accrail_lag	0.0171***	0.000	0.0215***	0.000	0.000894***	0.000
Constant	-0.337***	0.000	-0.839***	0.000	-1.064***	0.000
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-67.76		105.0		1258	
df_m	3		3		3	
chi2	187.2		192.4		72.00	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table D-5 MLM: ln(population growth rate) by center

popraten	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	-0.167***	0.000	-0.112***	0.000	0.000564	0.845
accroad_lag	0.0282***	0.004	0.000138	0.467	0.000643	0.310
accrail_lag	-0.00456	0.672	0.0232***	0.000	0.00117*	0.095
center_lag	0.280***	0.000	0.178***	0.000	0.0554***	0.000
1.center_lag#c.accroad_lag	-0.0311***	0.002	-0.000577	0.828	-0.00101	0.114
1.center_lag#c.accrail_lag	0.0164	0.121	-0.00224	0.529	-0.000460	0.517
Constant	-0.222***	0.005	-0.589***	0.000	-1.048***	0.000
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-49.62		120.7		1270	
df_m	6		6		6	
chi2	235.5		230.3		97.94	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table D-6 MLM: ln(population growth rate) by coastal

popraten	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
desln_lag	-0.131***	0.000	-0.0578***	0.000	0.00740***	0.000
accroad_lag	-0.00599***	0.000	0.000261	0.173	0.000209	0.499
accrail_lag	0.0287***	0.000	0.0130***	0.000	0.000659	0.175
coastal	0.123**	0.047	-0.0842	0.252	0.0303***	0.009
1.coastal#c.accroad_lag	0.00639***	0.000	0.00126	0.642	-0.000608*	0.055
1.coastal#c.accrail_lag	-0.0186***	0.000	0.00939**	0.024	0.000170	0.741
Constant	-0.404***	0.000	-0.800***	0.000	-1.082***	0.000
Observations	1,001		1,004		1,001	
Number of groups	10		10		10	
ll	-51.39		113.2		1263	
df_m	6		6		6	
chi2	229.5		210.7		86.46	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

APPENDIX E.

SPATIAL ERROR MODEL RESULTS

Table E-1 Spatial Error General model for ln(population density)

desln	**1990**		**2000**		**2010**	
	coef	pval	coef	pval	coef	pval
CONSTANT	1.706542	0.000	0.87944	0.001	-0.11976	0.026
DESLNLAG	0.715566	0.000	0.731617	0.000	1.024466	0.000
ROADLAG	-0.0029	0.006	0.000764	0.185	-0.00132	0.000
RAILLAG	0.030445	0.000	0.094986	0.000	0.003475	0.000
CAPITAL	-0.13789	0.305	-0.50979	0.013	0.016066	0.680
CHUANYU	-0.30546	0.028	-0.90267	0.000	-0.10798	0.005
GUANZHONG	-0.02587	0.880	0.383235	0.143	0.003377	0.945
HAIXIA	0.111327	0.507	0.784579	0.002	0.013035	0.792
LIAONING	0.09308	0.571	0.389198	0.122	-0.04967	0.278
PEARL	-0.52568	0.001	0.363155	0.122	0.058127	0.225
SHANDONG	-0.05376	0.754	0.333915	0.205	-0.00257	0.957
WUHAN	-0.10598	0.475	-0.2315	0.307	-0.12089	0.004
YANGTZE	-0.12233	0.399	-0.5467	0.012	0.075727	0.068
LAMBDA	0.566306	0.000	0.590487	0.000	0.139081	0.001
observations	1008		1008		1008	
r square	0.805131		0.795765		0.975614	

Y= ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table E-2 Spatial Error model for ln(population density) by center

	1990		**2000**		**2010**	
DESLN	coef	pval	coef	pval	coef	pval
CONSTANT	1.6186	0.000	1.107307	0	-0.05466	0.418
DESLNLAG	0.672707	0.000	0.682042	0	1.0006	0.000
ROADLAG	0.062521	0.001	0.000726	0.211	0.003087	0.181
RAILLAG	-0.00275	0.889	0.097081	0	0.003526	0.174
CENTER_LAG	0.66911	0.000	0.214793	0.207	0.190657	0.000
RDLAG_CTR	-0.0651	0.000	0.003926	0.659	-0.00438	0.059
RLLAG_CTR	0.01585	0.424	-0.00822	0.517	-0.00062	0.812
CAPITAL	-0.20017	0.118	-0.50378	0.012	-0.02064	0.595
CHUANYU	-0.41893	0.002	-0.89722	0	-0.14131	0.000
GUANZHONG	0.054574	0.738	0.382951	0.134	0.011371	0.812
HAIXIA	0.115025	0.473	0.762997	0.002	0.011367	0.814
LIAONING	0.103356	0.508	0.345064	0.161	-0.06645	0.138
PEARL	-0.47258	0.001	0.387305	0.094	0.03598	0.443
SHANDONG	0.021947	0.894	0.362609	0.158	0.001054	0.982
WUHAN	-0.07277	0.607	-0.20483	0.355	-0.12367	0.003
YANGTZE	-0.10033	0.476	-0.50746	0.018	0.045637	0.272
LAMBDA	0.55284	0.000	0.577437	0	0.12286	0.005
Observations	1008		1008		1008	
R Square	0.814482		0.795383		0.9761	

Y= ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table E-3 Spatial Error model for ln(population density) by coastal

	1990		**2000**		**2010**	
DESLN	coef	pval	coef	pval	coef	pval
CONSTANT	1.39695	0.000	0.779072	0.001	-0.20995	0.000
DESLNLAG	0.718721	0.000	0.761085	0	1.02465	0.000
ROADLAG	-0.00564	0.000	0.000772	0.189	0.000354	0.756
RAILLAG	0.046097	0.000	0.061832	0	0.002389	0.183
COASTAL	0.328785	0.008	0.139318	0.524	0.100018	0.005
RDLAGCOAST	0.005971	0.006	0.008383	0.354	-0.00184	0.116
RLLAGCOAST	-0.03425	0.001	0.00707	0.667	0.001821	0.340
LAMBDA	0.547571	0.000	0.665173	0	0.187887	0.000
Observations	1008		1008		1008	
R Square	0.801579		0.786487		0.975179	

Y= ln(population density) *** p<0.01, ** p<0.05, * p<0.1

Table E-4 Spatial Error General model for ln(population growth rate)

popratelnn	**1990**		**2000**		**2010**	
Variable	coef	pval	coef	pval	coef	pval
CONSTANT	-0.18789	0.018	-0.66728	0.000	-1.05201	0.000
DESLNLAG	-0.14001	0.000	-0.08834	0.000	0.006356	0.002
ROADLAG	-0.00212	0.000	0.000186	0.224	-0.00038	0.000
RAILLAG	0.015307	0.000	0.023615	0.000	0.000936	0.000
CAPITAL	-0.08065	0.165	-0.13286	0.024	0.003858	0.714
CHUANYU	-0.19017	0.002	-0.24299	0.000	-0.02999	0.004
GUANZHONG	-0.03387	0.645	0.086857	0.246	0.000838	0.949
HAIXIA	0.023452	0.749	0.199416	0.006	0.001041	0.938
LIAONING	0.002187	0.975	0.083126	0.250	-0.01349	0.276
PEARL	-0.3307	0.000	0.089195	0.179	0.016126	0.213
SHANDONG	-0.06744	0.352	0.091945	0.227	-0.00103	0.936
WUHAN	-0.08155	0.201	-0.08341	0.198	-0.0338	0.003
YANGTZE	-0.05978	0.346	-0.12791	0.040	0.017647	0.116
LAMBDA	0.457973	0.000	0.623659	0.000	0.128742	0.003
observations	1008		1008		1008	
r square	0.257972		0.439424		0.165065	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table E-5 Spatial Error model for ln(population growth rate) by center

	1990		**2000**		**2010**	
POPRATELN	coef	pval	coef	pval	coef	pval
CONSTANT	-0.17062	0.068	-0.62118	0	-1.03464	0.000
DESLNLAG	-0.16276	0.000	-0.09999	0	-0.00014	0.960
ROADLAG	0.020854	0.030	0.000171	0.267	0.00072	0.253
RAILLAG	0.003124	0.765	0.024764	0	0.001069	0.131
CENTER_LAG	0.253908	0.000	0.066087	0.149	0.052569	0.000
RDLAG_CTR	-0.0229	0.017	0.001633	0.49	-0.00109	0.084
RLLAG_CTR	0.00629	0.547	-0.00382	0.26	-0.0003	0.672
CAPITAL	-0.10557	0.056	-0.13216	0.023	-0.00626	0.550
CHUANYU	-0.23277	0.000	-0.24261	0	-0.039	0.000
GUANZHONG	-0.01406	0.840	0.089202	0.226	0.00317	0.806
HAIXIA	0.019197	0.783	0.194407	0.007	0.00074	0.955
LIAONING	-0.00614	0.926	0.073015	0.306	-0.01806	0.135
PEARL	-0.3047	0.000	0.093259	0.158	0.010158	0.423
SHANDONG	-0.03809	0.581	0.099792	0.183	8.17E-05	0.995
WUHAN	-0.07283	0.229	-0.07625	0.233	-0.03452	0.002
YANGTZE	-0.04964	0.421	-0.11825	0.056	0.009306	0.406
LAMBDA	0.429528	0.000	0.61613	0	0.11077	0.012
Observations	1008		1008		1008	
R Square	0.271391		0.439294		0.1818	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

Table E-6 Spatial Error model for ln(population growth rate) by coastal

	1990		**2000**		**2010**	
POPRATELN	coef	pval	coef	pval	coef	pval
CONSTANT	-0.34311	0.000	-0.71905	0	-1.07769	0.000
DESLNLAG	-0.12801	0.000	-0.08182	0	0.006395	0.001
ROADLAG	-0.00448	0.000	0.000179	0.249	0.000101	0.746
RAILLAG	0.015932	0.000	0.01649	0	0.000647	0.186
COASTAL	0.061073	0.257	0.064995	0.276	0.027661	0.004
RDLAGCOAST	0.004773	0.000	0.003391	0.157	-0.00053	0.097
RLLAGCOAST	-0.00904	0.051	-0.0007	0.875	0.000475	0.361
LAMBDA	0.382175	0.000	0.686622	0	0.178234	0.000
Observations	1008		1008		1008	
R Square	0.2255		0.420801		0.150498	

Y= ln(population growth rate) *** p<0.01, ** p<0.05, * p<0.1

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