Public Infrastructure in China
Explaining Growth and Spatial Inequality

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Public Infrastructure in China:
Explaining Growth and Spatial Inequality

Public Infrastructure in China:

Explaining Growth and Spatial Inequality

Proefschrift

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door

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List of original publications

This thesis is based on the following original articles, which are referred to by their chapter numerals in the text:

Chapter 2: Yu, N.*, de Jong, M., Storm, S., Mi, J., Transport infrastructure, spatial clusters and regional economic growth in China. *Transport Reviews*, 2012, 32(1), 3-28

Chapter 3: Yu, N.*, de Jong, M., Storm, S., Mi, J., The growth impact of transport infrastructure investment: a regional analysis for China (1978-2008). *Policy and Society*, 2012, 31(1), 25-38

Chapter 4: Yu, N.*, Yu, B., de Jong, M., Storm, S., Does educational inequality matter for China's economic growth? *International Journal of Educational Development*, 2015, 41, 164-173

Chapter 5: Yu, N.*, de Roo, G. de Jong, M., Storm, S., Does the expansion of a motorway network lead to economic agglomeration? Evidence from China. *Transport Policy*, 2016, 45, 218-227

Summary

Public infrastructure is often mentioned as a key to promoting economic growth and development. This belief has been supported by the observation of rich countries, such as the U.S., Japan and those in Western Europe, where plenty of infrastructures developed during times of rapid economic growth. China has been one of the world's fastest-growing and most important emerging economies in recent decades with good performance of public infrastructure. However, China's transition to a market-based economy has created new problems, among which is the growing regional inequality in per capita income. The interior region (near west) and far western regions lag far behind the coastal region in economic progress. Both theoretical and empirical evidence is provided to support the public infrastructure-led growth hypothesis, it is questionable, however, whether investment in infrastructure has been helpful in spurring economy, and in reducing the growing coastal-interior gap in China, considering that plenty of large infrastructure projects have been constructed or planned in the less-developed interiors. Therefore, this study explores both *if* and *how* public investment in infrastructure

could help explain the economic growth and increasing regional disparity in China.

To answer these questions, the book is organized in the following way: in chapter 1 the regional distribution pattern of the public infrastructure and economic development in China is introduced, the problem of infrastructure-led growth and disparity is diagnosed, and the research question is posed; in chapter 2 the causal linkages between transport infrastructure and economic growth in China are determined at national and regional levels separately; after identifying the causality between transport infrastructure and economic development, chapter 3 estimates the impact of transport stock on overall economic growth, and on growth at the regional level as well; the long-run effects of education attainment and its distribution on China's growth in China are estimated in chapter 4; chapter 5 examines the distributive impact of public infrastructure (both transport infrastructure and education), highlighting the role of road infrastructure in narrowing China's spatial concentration and inequity; chapter 6 provides a synthetic answer to the research question based on all theoretical and empirical study in the previous chapters.

Therefore, rather than providing recommendations for the Chinese governments about how much they should invest in infrastructure projects, this book aims at understanding the real role of public infrastructure in China's growth and disparity, and illustrating how public infrastructure investment plan changes can achieve economic efficiency and spatial equity.

Chapter 1

Introduction

1.1. Regional patterns of economic growth in China

China started its industrialization process in the early 1950s. However, growth performance before and after 1978, the year in which China's economic reform started, differs significantly. Prior to 1978, the average growth rate of real per capita gross domestic product (GDP) was a modest 3% a year, while China's growth in per capita GDP has accelerated to a rate in excess of 10% per year in the post-reform period (State Statistical Bureau of China, 2011). With this, China has become one of the world's fastest-growing economies. Nevertheless, China's transition to a market-based economy has created new problems, among which is the growing inequality in real income per capita between coastal and interior provinces. Indeed, in recent years, China has become one of the most economically unbalanced countries in the world, as presented by the national comparison of the Gini index shown in Table 1-1. In the year 2009, the ratio of real per-capita GDP between the wealthiest (Shanghai) and the poorest province (Guizhou) was 8.65 in China (OECD, 2010). By comparison, among the major regions of the United States in 2009, the ratio of the highest to lowest regional per-capita GDP was only 1.3 (United States Bureau of Economic Analysis, 2010). In India for 2009, where is also a typical developing country with huge population, the comparable ratio (in nominal terms) was only 4.5[1]. The discrete coefficients of disposable income per capita during the period of 1978-2010 also appear to an obvious upward trend, from 0.18 in 1978 to 0.29 in 2010, indicating growing disparities among China's provinces[2].

Table 1-1. Comparison of Gini indexes between countries

Country	2000-2004	2005-2009	Country	2000-2004	2005-2009
China	-	0.53-0.61*	United States	0.41	0.45
Brazil	-	0.53	Italy	0.36	-
India	0.34	0.37	Germany	0.28	-
Indonesia	0.38	-	Canada	0.33	-

Note: The Gini index measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of 0 represents perfect equality, while an index of 1 implies perfect inequality. Sourced from 'Income inequality in today's China', 2009. Others via the world bank International Development Association (IDA) data.

[1] Data sourced from the World Bank International Development Association.

[2] Data are from Sohu Finance, available on line: http://business.sohu.com/20121105/n356704530.shtml

Figure 1-1. Definition of China's three macro-regions

Note: The definition of China's three macro-regions sourced from 'the seventh five-year plan of national economy and social development' supposed by the Central Committee of the Communist Party of China.

To better characterise regional economic development, the provinces as well as provincial-level municipalities have been grouped into three regions, namely the Eastern Region, the Central Region, and the Western Region (as shown in Figure 1-1), as proposed by the Central Committee of the Communist Party of China in 1986. The three regions will also be adopted for data analysis in the current thesis. The reasons are two-fold. Firstly, this region division considers both of geographic location and economic development level, which are the key factors that we highlight in this study. Secondly, the division of the three regions are the basis for making governmental development strategies such as 'West Development Strategy' and 'Rising of the Central Regions Strategy'. As a result, the three regions allow us to put the regional economic growth and public policies together in the current thesis for explaining China's economic growth and regional disparity.

On average, the eastern provinces had much better economic performance than inland (i.e., both the central and western) provinces (State Statistical Bureau of China, 2011). This growth concentration along the coastline has widened regional income disparities in the last decades. Thus, how to reduce these disparities appears to be one of the important policy challenges that China now faces in order to maintain its long-term economic development and societal stability.

The reasons for unequal regional development in China are complex. The natural geographic environment and biased development policies implemented since the economic reform are usually regarded as the main explanations, as Table 1-2 describes. The coastal region has a better economic performance in terms of per capita income than the interiors since the foundation of the People's Republic of China (PRC). China has experienced growing cross-regional inequality since 1978, the start of the reform and opening-up policy, especially after the financial decentralization in 1994. Meanwhile, besides the various geographical and environmental conditions, China has long executed a biased development policy, the so-called 'Coastal Priority Development Strategy.' This was proposed by Deng Xiaoping in 1979 after the economic reform started. More and more resources (both investment and human capital) gathered in the coastal areas. Since 1998, the Chinese government has made a greater effort to develop interior regions through financial policies such as the 'Western Development Strategy' and 'Revitalizing Northeast Old Industrial Base,' but the economic benefits have remained far more modest than expected (Zhou, 2009). The Chinese government may hope to see the rapid growth of the coastal provinces, helping spur the development of the central and western regions. Nevertheless, there has been little impact on the inland regions, even though most coastal provinces have witnessed a favorable development. Accordingly, the pronounced disparity between the coastal and inland provinces in China has increased in the past decade.

Figure 1-2 displays the visual evolution of economic growth' spatial distribution during the period of 1952-2010, providing important evidence of the increasing inter-regional disparity in China. Three clear features can be extracted from Figure 1-2 to explain the change of China's growth distribution.

(1) In the early period of the PRC's foundation, there appears to be a balanced growth distribution among regions. Coastal cities like Beijing and Shanghai have a better development than the interiors. Some northern provinces, such as Heilongjiang, Inner Mongolia and Xinjiang have shown a higher level of economic development because of various types of nature resources located in the northern provinces.

2) As China's growth "miracle" started in the coastal region in the 1990s, more and more economic activities clustered in the eastern; the south coast had an especially outstanding performance. This of course meant that the ranking of the other interior regions (especially the northeastern and western provinces) declined.

(3) With the deepening of market-oriented reform, the income inequality between coastal and interior regions has been very obvious since 2000. In the year of 2010, all the high income provinces (expect Inner Mongolia, where has an outstanding performance due to the exploitation of energy) located in the eastern region. The spatial development pattern of core-periphery (coast-interior) has already firmly taken shape in China.

Table 1-2. The definition of China's three macro-regions and their social–economic characteristics

Three macro-regions	Social and economic characteristics
Eastern Region (consisting of 9 provinces and 3 municipalities)	Geography: Most provinces of the eastern region are located near the coast, which is a significant advantage for international trade. Society: A mass of resources and capital has flowed to the eastern region because of the biased development policy since 1978. Thus, there is a well-educated labor force, advanced technology, better medical conditions and improved urban infrastructure. Economy: Most provinces in the eastern region, where most of China's economic activities are clustering, have been leading in economic growth in China for a long time.
Central Region (consisting of 9 provinces)	Geography: The central region is the connection plane of the other two regions. Society: The connecting provinces (Shanxi, Henan, Anhui, Jiangxi, Hubei and Hunan) account for 10.7% of the country's total land area, but carry 28.1% of the total population. Economy: The economic growth ratio of the central region has been invariably lower than the national average ratio, with the gap continuing to widen in recent years.
Western Region (consisting of 9 provinces and 1 municipality)	Geography: Most provinces of the western region are located in the western part of China, suffering from drought, difficult climatic conditions and having uninhabitable mountainous areas. Society: The territories inhabited by ethnic minorities, such as Tibet and Xinjiang, have experienced social conflicts partly due to low levels of social and economic development and strong independence movements. Economy: Average income levels in the western provinces have been very low, lagging far behind in economic growth and living conditions; however economic development has begun to take off after the 'Western Development Strategy' carried out in 1998.

Note: Table is from Yu et al. (2012)

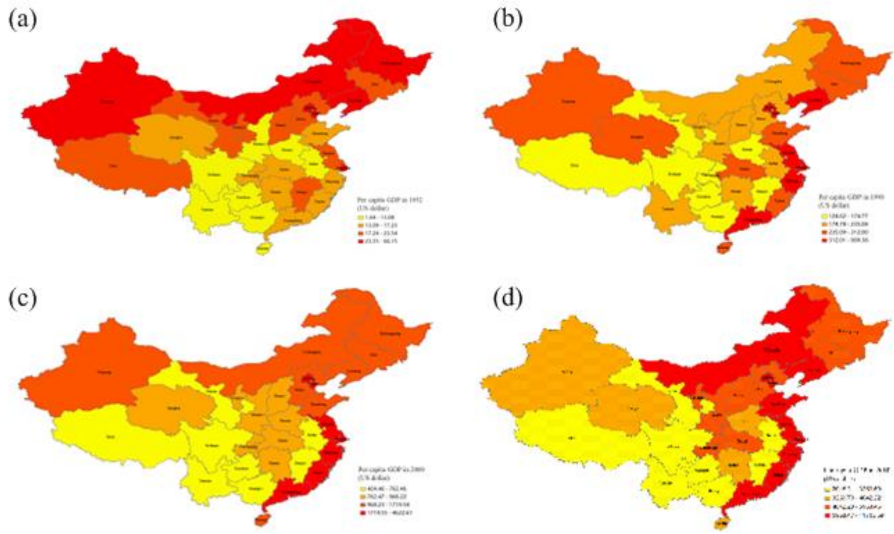

Figure 1-2. The evolution of economic spatial distribution in China: a) 1952; b) 1990; c) 2000; d) 2010

Note: The figures show each province's per capita GDP, and the unit is US dollar at current prices. The groups from the lighter color to the darker color indicate the per capital GDP from lower to higher levels. Data collected from the authors' own calculations based on the data from the China City Statistical Yearbooks (2001, 2011). Map data sourced from the China Foundational Geography System.

To summarize, despite high overall economic growth rates during the past several decades, the high and rising income inequality between coastal and interior provinces has become a major policy challenge that the Chinese authorities now face. Thus, it is essential for the government to identify the causes in order to address the problem, which is why we propose this research project - to provide an investigation into the important drivers of regional inequality.

For an emerging economy like China's, cheap labour and better infrastructure played an essential role at the initial stages of development (Demurger 2001; Hu and Liu, 2010). With a seemingly unlimited supply of cheap labour from the rural sector, public investment in infrastructure played a key role in the process of China's development. Meanwhile, public infrastructure is often regarded as the key political component to reduce regional disparity, since the availability of public infrastructure might be helpful in facilitating communications between provinces, even though the result of investment policy (especially for distribution) is still unknown. In order to contribute to the understanding of the determinants of China's inter-regional disparity, this study will emphasize ***the role of public infrastructure in explaining China's growth and increasing regional inequality***.

1.2. Disparity in public infrastructure development among Chinese regions

With its booming economy, China has significantly improved the country's public infrastructure over the past three decades. This includes progress towards increasing public spending on infrastructure at a level that is more in line with China's development needs (OECD, 2006). All types of infrastructure have witnessed great improvements. For the electricity infrastructure, total electricity output was roughly 4201.76 TWh in 2010 as compared to 621.20 TWh in 1990. The postal and telecommunication services also improved significantly during recent decades. In 2010, each post office served an average of around 18,000 people; nearly 98.96 percent of administrative villages had a post office. Mobile telephones numbered about 74 per 100 persons while this figure was only 7 per 100 persons in 2000 (of course the fast improved technology of mobile telephones was also a principal reason for this dramatic increase). Broadband Internet access was available in 80.11 percent of administrative villages by the end of 2010. The popularization rate of the Internet reached 34.3% in 2010 while the number was 4.6% in 2002 (China Statistical Yearbook, 2011). By the end of 2010, the total length of the road network was approximately 4,008 thousand kilometers, of which 74 thousand kilometers were expressways, compared with a figure of 1,698 thousand kilometers in total and 19 thousand kilometers for expressways in 2001.

However, considering China's large scale and development strategies in different times[3], important regional differences arise in public infrastructure. This is especially true for network infrastructures, which have a substantial impact on both the local economy and those of neighbouring regions; they have quite a different performance in the coastal areas than in the more primitive interior provinces. In this project, we will take transport infrastructure (important physical infrastructure) and education (important social infrastructure) as examples of network infrastructure to show the ***disparity in public infrastructure development*** among Chinese regions.

Spatial distribution of transport infrastructure

Since the foundation years of PRC, national centralized decision-making framework applied to all kinds of investments, including those in infrastructure construction. The country's transport infrastructure investments, which were planned and executed mainly at the national level, did not fully fulfill the basic needs of society development and citizens' travel. At the beginning of the 1980s, China was a relatively poorly endowed country in terms of transportation networks.

During the development process, transport infrastructure

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[3] Various economic policies make profound impacts on the spatial pattern of China's infrastructure construction.

investments have become important and necessary in order to facilitate the mobility of economic activities. Chinese governments thus set transport infrastructure sectors as key sectors to be financially supported. Transport infrastructure investment accounted for less than 1.79% of GDP in 1978; however, this ratio increased to 5.64% by 2009. Meanwhile, the proportion of transport infrastructure investment in national public infrastructure increased to 42% in 2009 from 23% in 1978 (Wu, 2009). Altogether, China has achieved tremendous progress in its transport infrastructure construction since governments at different levels have made huge investments in it. However, the fiscal decentralization process begun in 1994 has given local governments more autonomy on fixed-assets investment. In this case, the wealthier coastal provinces could provide better transport infrastructure while less-developed western provinces had limited public investment in their transport equipment. Consequently, during the post-reform period, the gap in transport infrastructure between regions has continued to expand.

Table 1-3 gives a broad overview of regional transport infrastructure endowment disparities including all modes of transport. The most pronounced regional difference in the availability of transport infrastructure is found between coastal and western provinces. The coastal-inland divide is particularly clear in road network density. The road network density in the eastern region is twice as large as that of the western region. As roads have been developed rapidly during the past decade, this inequality illustrates the uneven development that occurred throughout the reform process between coastal and noncoastal provinces. Meanwhile, among noncoastal provinces, those central provinces that are located next to coastal provinces are relatively well endowed in terms of transportation facilities. On the opposite end, transport network density remains very low in the remote western provinces. Besides the regional quantity disparity of transport infrastructure, quality is also unequally distributed among different regions - the central and western regions are poorly served by expressways.

Table 1-3. Average transport infrastructure availability by regions, 2000-2010

Regions	Transport network density (km/1000km^2)		
	Road		railway
	Total	Expressway	
Eastern Region	1036.02	24.91	18.56
Central Region	349.37	63.46	7.57
Western Region	113.63	1.53	4.02

Note: Data is collected from the author's calculation based on data from the China Statistical Yearbook for Regional Economy 2001-2011.

Figure 1-3 provides evidence of the transport infrastructure concentration (both railway and motorway) along the coastline. The eastern provinces had higher road and railway network density than the interiors at the end of 2010. What is noteworthy is that the spatial distribution of transport infrastructure also shows clear regional clusters. The relatively well-developed eastern region owns better transport facilities.

We also provide the Choropleth mapping to show the spatial distribution characteristics of the road network in 2010, as shown in Figure 1-4. Two distinguishing points can be summarized from this choropleth map. First of all, at the end of 2010, most provinces in the last group (with road density between 114-224 km/100km^2) that are relatively well served are located in the coastal provinces. Secondly, the clusters of road networks diminish from upper eastern China to lower western China; all provinces in the first group are found in the western region, as the road density is much lower the closer the provinces are to the west.

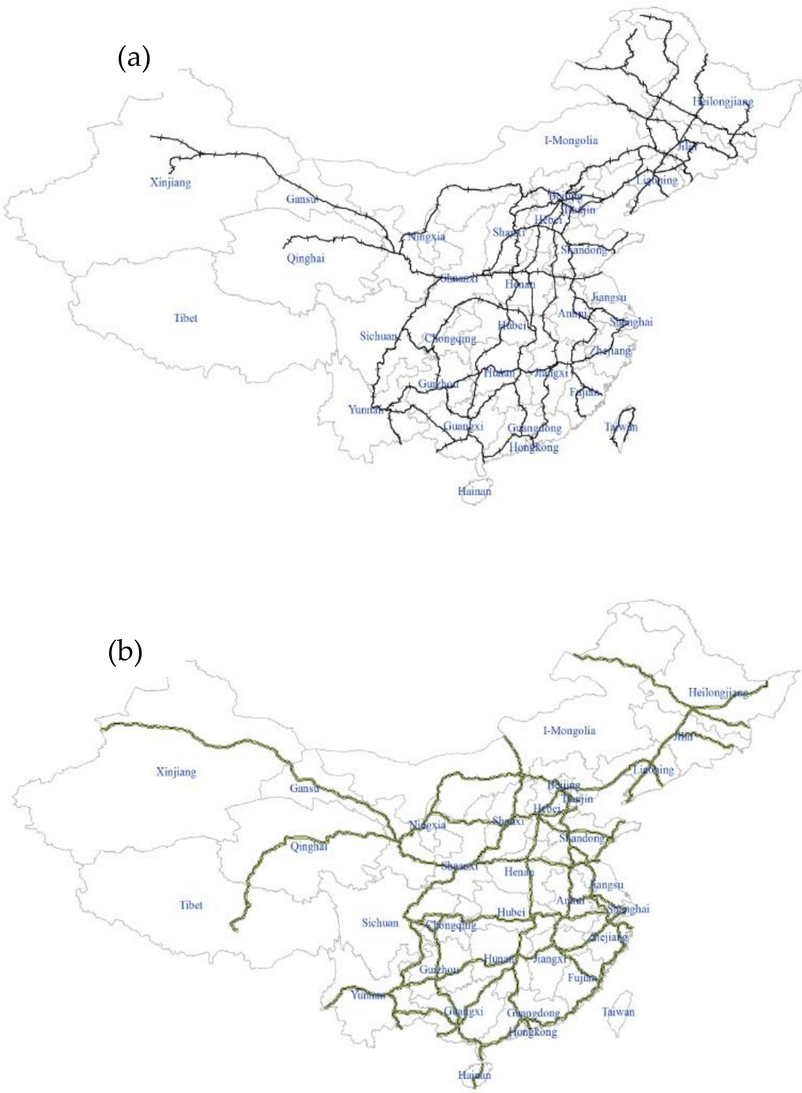

Figure 1-3. Spatial distribution of motorway (a) and railway (b) networks in China in 2010

Note: Information of transport network sourced from China Foundational Geography System.

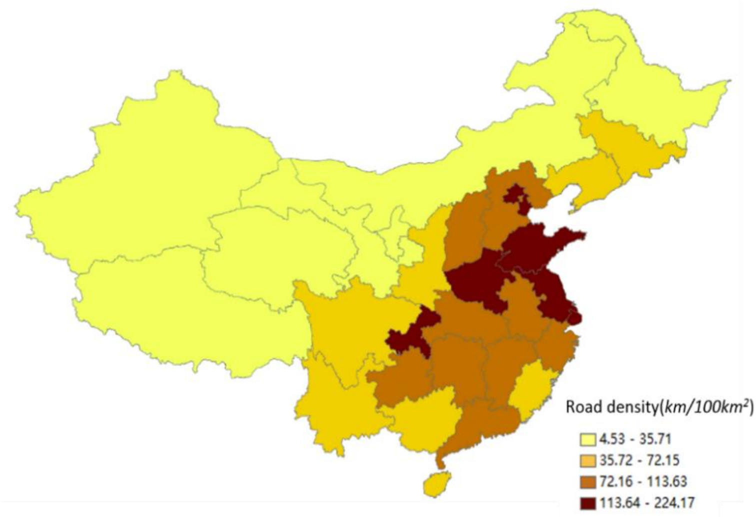

Figure 1-4. Spatial clusters of road infrastructure in China in 2010

Recently, more and more transport projects are under construction or preparation, even though China has slowed down its development pace. 42 integrated transportation hubs are expected to develop in the coming years, 19 of which are located in the coastal regions, as Figure 1-5 illustrates. Setting up inter-regional transportation networks is the main focus in decision-making about transport investment strategies.

In general, China has attained great achievements in transport infrastructure construction and its national comprehensive transportation network has begun to take shape in recent years. Nevertheless, there exists a wide variation in transport infrastructure facilities among Chinese regions, which gradually decrease in density from eastern China to western China. The spatial distribution pattern of transport infrastructure networks is similar to the development distribution of these regions. Transport facilities are concentrated along the coastline, whereas the overall transport network density remains very low in remote western provinces.

Figure 1-5. 42 developing integrated transportation hubs in China

Note: Figure sourced from Mu (2013).

Spatial distribution of education recourse

Besides transport infrastructure, education has been emphasized by the Chinese government for the past several decades. The Chinese government started to heavily invest in education in the 1950s, providing a nine-year compulsory education for all citizens. As a result, Chinese people enjoyed a better education status than their counterparts in lower-income countries such as India and Vietnam, even before the policy reform (Lopez et al., 1999). Since the economic reform in 1978, and especially after the fiscal reform of 1994, China invested heavily in its education sector. Figure 1-6 displays the upward trend in education investment during the post-reform period. Public investment in education in 2010 was approximately 35 times greater than in 1978 (at 1978 constant prices). An analysis of educational expenditures over time also shows that more resources were spent in the education sector since the economic reform. For example, during the 1950-1978 period, government education expenditures (budgeted funds) amounted to 6.50% of total government expenditures and 2.20% of the national income. But during the first decade of the new millennium, it rose to 11.01% of total government expenditures and 2.88% of the national income (Fleisher et al., 2010). Consequently, China's education system has experienced remarkable changes both quantitatively and qualitatively. The illiteracy rate of the Chinese population has dwindled from 33.58% in 1964 to 4.08% in 2010, and the number of people attending secondary schools per 100 persons rose to 39 in 2010 from 5 in 1964 (NBS, 2011).

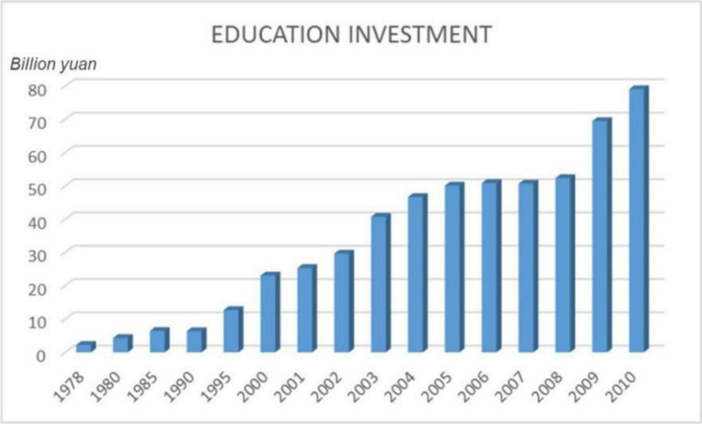

Figure 1-6. Trend of education investment in China

Note: The investment in education is at the 1978 constant price.

Along with the increasing education investment and expansion in higher education, there was an obvious disparity in educational resource distribution among Chinese regions during the past two decades. This is explained by the fact that public schools are funded mainly at the local level; wealthier provinces tend to produce more education investment per capita than poorer provinces. Resource constraints differentially affect access to schools for individuals in different areas of China. Particularly hard hit are children in rural areas and those in the West. Figure 1-7 shows the share of governmental spending on education among China's three macro-regions in 2010. The coastal provinces account for 48.30% of the national financial expenditure on education, twice the amount of the western region. From a perspective of education expenditure per capita, the ratio of eastern, central and western regions is 1.59:0.89:1 (using the western region as the benchmark). Hence, the regional disparities in education expenditures appear to be very distinct from the view of both total expenditures and investment per capita.

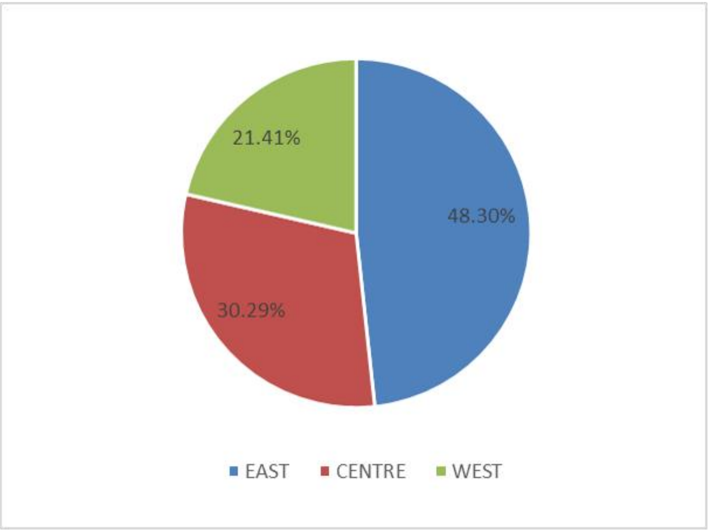

Figure 1-7. Regional share of national financial expenditures on education in 2010

Meanwhile, the distribution of educational resources has clear qualities of spatial clustering. Figure 1-8 depicts the geographic location of China's 39 leading universities (the universities in the *Project 985*[4] list provided by the Chinese government). We can see that most of the leading universities are located in Beijing, Shanghai

[4] Project 985 aims to develop a number of leading universities in China into world class universities, proposed by the Chinese government, named after the date of announcement, May 1998. There are 39 universities on the project list.

and other coastal provinces while the only 6 *Project 985* universities (39 in total) are found in the 10 provinces of western China. Moreover, China's universities are experiencing the 'Matthew effect', whereby the powerful institutions become stronger and the weaker universities become even more vulnerable (Tang and Miao, 2014). The top universities received a large number of financial support while 'ordinary' universities are becoming less and less competitive, since more resources and prominent people are gathered in the leading universities. Thus, more and more educational resources are gathering in these eastern provinces where there are more leading institutions because they have obtained a larger public investment from the state.

In general, educational attainment has been developed to a much better level in China in recent decades. The average number of schooling years has gradually increased since the 1950s, from 5.2 in 1949 to 10.23 in 2010. Increasing amounts of people now have the opportunity to achieve higher education, and a well-educated and skillful workforce will lead China to higher productivity and growth. Nevertheless, the existing inequality in education between regions has widened to some extent. Notably, Chinese authorities may not realize the importance of education for the poorer western areas; they invested substantially in the construction of transportation infrastructure in those western provinces while less public funds were devoted to education.

In summary, both transportation facilities and education levels in China have seen great achievements that alleviate infrastructure-related constraints, even though the infrastructure provision has been accompanied by provincial development disparities. In order to explore the role of public infrastructure in explaining China's growth and inter-regional inequality, this research project will focus on disparities in infrastructural resources across regions; especially transport infrastructure and educational resources as determinants of increasing regional economic inequality.

Figure 1-8. Spatial distribution of China's leading universities

1.3. Theoretical overview

1.3.1 Definition of infrastructure

Generally speaking, infrastructure refers to 'the fundamental facilities and systems serving a country, city or area, including the services and facilities necessary for its economy to function' (World Bank, 1994). This notion includes both physical components and the "softer" infrastructure, such as information systems and knowledge bases. Two categories of infrastructure are widely accepted, namely the physical and the social. Physical infrastructure refers to part of an economy's capital stock, which could facilitate economic production (e.g., electricity, roads and ports). The physical infrastructure could also serve as inputs to the production process. On the other hand, social infrastructure encompasses non-tangibles, such as education and technology; policy, regulatory and institutional frameworks; governance mechanisms; and medical care, which could support the development and operation of physical infrastructures (Bivens, 2014).

In this study, we will take transport and education infrastructure as examples of physical and social infrastructure, respectively, to explain how these infrastructures impact the national economy. Transport infrastructure, understood as mainly including roads, railroads, airports and seaports, an important part of the country's physical infrastructure that has often been claimed to be an essential determinant of productivity and economic growth. And education, as a vital component of the social infrastructure, plays an irreplaceable role in the development process.

We have chosen transport and education as examples of infrastructure in this book for the following reasons. Firstly, transport and education investments account for a large portion of the entire state financial expenditure in China, which is approximately 20% over the 2000-2010 period. Secondly, both transport and education infrastructures have great effects on the nation's economy and are the foundation of economic activities and economic growth. Thirdly, besides the common characteristics of public infrastructure (longevity, scale, inflexibility and high investment costs), both transport and education infrastructures have a clear spatial spillover feature: some effects induced by these infrastructures will extend outside the limits of a single area, generating effects in neighboring territories. These infrastructures would affect both economic growth and regional disparity.

Therefore, transport and education infrastructures can be regarded as critical cases and these two infrastructures are the most appropriate candidates for analysis under the spatial framework.

1.3.2 Relevant theories

1.3.2.1 Why does transport infrastructure matter?

There are a plenty of reasons why developed transport infrastructure is advantageous for economic growth. Improvements in transport infrastructure could enhance overall economic performance by reducing transportation costs and promoting market integration and factor mobility, facilitating firms transferring goods from firms to retailers, and households engaged in commuting etc. Lack of adequate transport infrastructure significantly inhibits local economic performance by constraining labor and material migration. Lakshmanan (2011) provides an explanation on the wider economic benefits of transport infrastructure investments, as depicted in Figure 1-9. As the figure shows, lower transport costs and time-savings would benefit from transport operating production sectors. Increased regional accessibility leads to higher efficiency caused by scale economies, market expansion and specialization. Over time, transport service improvements would encourage improved labor supply and activate some interconnected economy processes.

It is worthwhile underlining that new economic geography models emphasize the importance of transport costs in explaining the industries location (Krugman, 1991; Fujita et al., 1999). Transport infrastructure improvements could change the spatial distribution of economic activity by coordinating the concentrating forces (large market size and agglomeration economies) and dispersing forces (high factor costs and competition). Better transport connections can make areas of lower economic activity more attractive for firm location as they gain better access to markets in the core areas. But, at the same time, competition from firms in economic agglomerations may increase, as they are now able to more easily supply locations at a distance and benefit from cost and demand linkages. Transport facilities would yield expanded production and realize economic restructuring in the process of industrial convergence or industrial divergence, which may augment the overall growth.

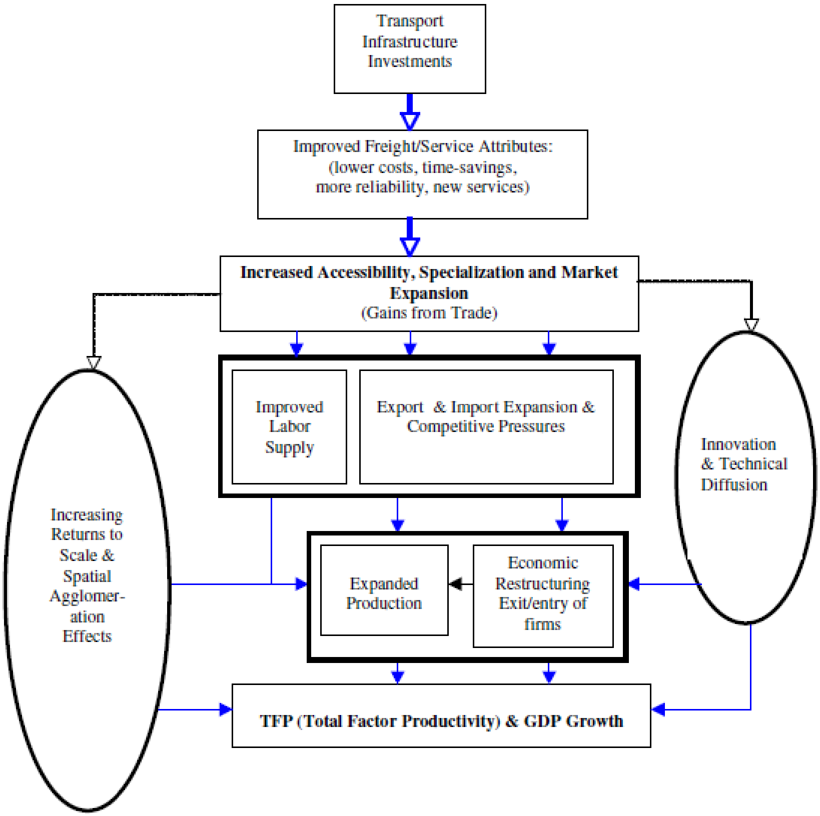

Figure 1-9. The interaction mechanism of transport infrastructure and economic growth

Note: This figure sourced from Lakshmanan (2011), 'The broader economic consequences of transport infrastructure investments'.

Based on these theoretical arguments, Banister and Thurstain-Goodwin (2011) suggest that transport investment affects the local economy at three different levels: output and productivity (at the macro-level), agglomeration economies and labor market effects (at the meso-level) and land and property market effects (at the micro-level). Given that our research project focuses on the growth and disparity effects of public infrastructure, we will emphasize the transport-economy nexus at the macro-level and meso-level (to some extent) in this book.

1.3.2.2 Why does education matter?

Theoretical models of education-led growth are built around the hypothesis that human knowledge and skills directly raise productivity and increase an economy's ability to develop and to adopt new technologies (Romer, 1986; Barro, 1990). In the new neo-classical growth theories, externalities with the development of technical knowledge are considered in order to endogenize innovation. Technological change is treated as a separate factor in the aggregate production function. Here, the importance of education for promoting economic growth is reaffirmed. Long-term economic growth improves as a result of an increase in the rate of technological change. Technological change increases when there are more highly educated workers. Thus, the importance of education, and specifically 'knowledge', for facilitating the development of new technologies and as a source of endogenous growth is emphasized to explain one nation's economic development. Further, the new growth theories attach a key role to education (broadly to knowledge) as essential to the engine of economic growth.

Direct and indirect effects of education are shown in Figure 1-10.

Key assumptions underlying the diagram are:

1) education results in learning – it is not merely a "signal" of worker quality;

2) demand within the economy is sufficient to consume higher levels of output resulting from productivity gains;

3) monetary and fiscal policy is sufficiently responsive to meet the demands of a growing economy (to prevent deflation, the money supply grows at a rate equal to the growth rate of GDP).

Direct effects of education such as increased individual wages follow from the assumption that education results in increasing a worker's productivity. If workers are paid the value of their marginal product, it follows that better-educated workers should earn higher wages.

In addition to the direct effects of education, a number of indirect effects can be also identified in the literatures. Studies have found a "positive effect of mother's schooling on her children's health in developing countries." Healthier children may be more productive than unhealthy children and the result may be higher performance in school. Similarly, better-educated parents tend to make more informed decisions with regard to family planning – the result being smaller family sizes. Smaller family size enables more parental involvement in each child's education (as parents' time is scarce).

Altogether, education could affect economic growth by:

- Improving labor productivity
- Facilitating the adoption and implementation of new technology developed exogenously
- Promoting the domestic production of technological innovations
- Replacing other production factors
- Externalities related to education, health and population growth

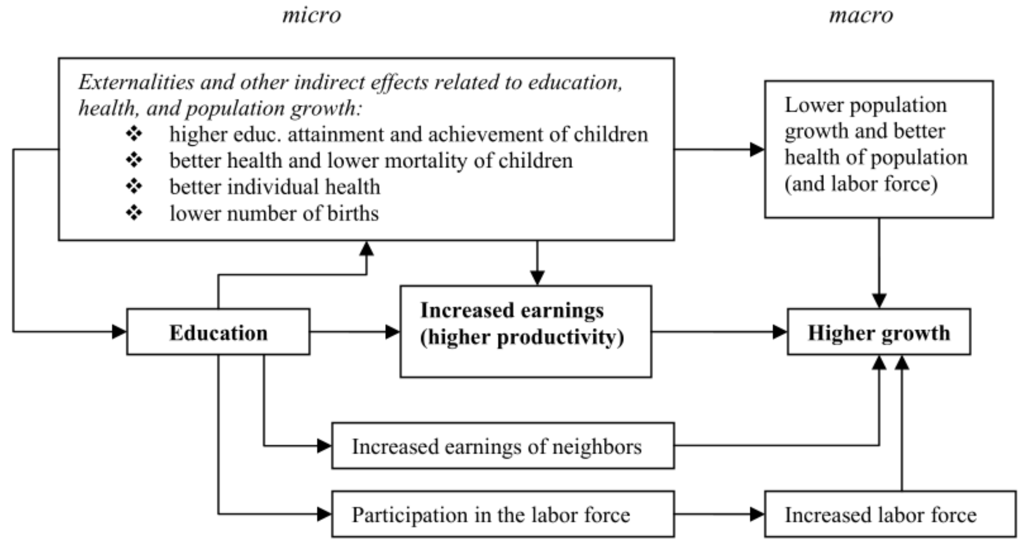

Figure 1-10. The growth impact of education at both micro and macro levels

Note: This figure sourced from Michaelowa, Katharina. (2000) "Returns to Education in Low Income Countries: Evidence for Africa."

1.4. Literature review

1.4.1 Transport infrastructure-economy nexus

During the past two decades, numerous empirical studies have been implemented to examine the impact of transport infrastructure on economic development. Sparked by the influential work of Aschauer (1989), a massive amount of research has examined the contribution of transport infrastructure to economic growth. Previous theoretical analysis and empirical evidence have significantly improved our understanding of the growth impacts of public transport improvements (Chatman and Noland, 2011) and the wider economic benefits of transport infrastructure investment (Bhatta and Drennan, 2003; Lakshmanan, 2011; Vickerman, 2008).

Table 1-4 displays recent macroeconomic studies on estimation of output elasticity from transport infrastructure investment. These studies tend to demonstrate some fairly strong positive links between transport infrastructure, productivity and economic growth, and some indicate very substantial rates of return (Demurger, 2001; Cohen and Morrison; 2004; Ozbay et al., 2007; Jiwattanakulpaisarn et al., 2011, 2012). Nevertheless, the wide range of output elasticity and, in some cases, even the opposite sign of the transport-economy link reveals the uncertainty of transport infrastructure-led growth hypothesis (Cantos et al., 2005; Berechman et al., 2006). The empirical evidence on transport-led growth hypothesis is neither unanimous nor conclusive.

Meanwhile, some studies attempt to investigate the impact of transport infrastructure on economic growth in China. Fleisher and Chen (1997) tried to find any significant impact of transport infrastructure on total factor productivity and economic growth during the period of 1978–1993, but failed. Demurger (2001) investigated the relationship between public infrastructure and economic growth in China using panel data from a sample of 24 Chinese provinces from 1985 to 1998, and found that transport facilities are a key differentiating factor in explaining the growth gap among Chinese provinces. Ma and Li (2001) analyzed the effects of the transport infrastructure capital stock on the private sector with the aid of an econometric model during the period of 1981 to 1998, and the output elasticity was found to be 0.55. Lou (2003) made an empirical investigation of the link between China's transport infrastructure investments and its long-term economic growth. The output elasticity of transport infrastructure capital from 1949 to 1999 proved to be 0.23. Zhang (2007) found the elasticity was 0.11 using the data over the period of 1993–2004. Hong et al. (2011) provided strong evidence that transport infrastructure plays an important role in economic growth, however the economic contribution varied with the different transport modes. Generally, most Chinese cases have revealed the positive economic contribution of transport investment, even though the results show great diversity.

From a policy perspective, although most empirical studies confirm a positive impact of transport infrastructure on growth, there is still a great deal of controversy concerning the direction and magnitude of growth-enhancing effects of transport infrastructure. The divergence in findings makes it difficult to draw out unequivocal policy lessons (Bhatta & Drennan, 2003; Lakshmanan, 2011; Romp & de Haan, 2007). Thus, the debate concerning the transport-economy nexus continues to develop.

One important issue of the underlying problems investigated in the transport-led growth topic is **causality**. There must be a set of causal relations between transport investment and economic development since it is not unreasonable to assume that the developed areas with higher GDP prefer to invest more in transport investment. With the economic growth and increasing job opportunities, many enterprises and families re-locate, which may lead to a change in site attractiveness and then a change of accessibility demand. The governments have to make corresponding transport infrastructure policies to achieve economic goals on the analysis of evaluating transport network and local accessibility in different regions. These policies will remodel the scale and direction of transport infrastructure investment. From this perspective, exploring the existence and direction of causality between transport investment and economic growth is necessary for revealing the 'real' growth impact of transport infrastructure investment. However, research efforts to empirically identify the existence of these causal links have been minimal. Indeed, the existing literature about China gives us little insight into whether the causal relationship exists in China and how the causality change across regions.

Table 1-4. Recent macroeconomic studies on estimation of output elasticity from transport infrastructure investment

Authors	Transport infrastructure indicators	Geographic level	Findings
Boarnet (1998)	Street-and-high capital	California counties	County output: own county's street-and-high capital: 0.236-0.300; neighbor countries' street-and-high capital: -0.806 to 0.125
Pereira (2000)	Highways and streets	Time series data of USA	Highway investment has a positive impact on the private output; output elasticity:0.0055
Demurger (2001)	Overall transport network density	Chinese provincial level	Output elasticity: 0.166-0.754
Cohen and Morrison Paul (2004)	Highway infrastructure stock	US state level	Significant beneficial productive effect of infrastructure investment is confirmed, enhanced by the spillover effect
Cantos et al. (2005)	Individual and aggregate capital stock of transport	Spanish regional level (17 regions)	Aggregate transport stock: -0.106 to 0.225; roads: -0.063 to 0.286; ports: 0.029-0.562; airports: -0.016 to 0.109; railways: -0.045 to 0.133
Berechman et al. (2006)	Highway capital stock	US state level, county level, municipality level	Output elasticity of highway infrastructure on economic growth: state level: 0.3; county level: 0.34; municipality level: -0.01
Moreno and Lopez-Bazo (2007)	Stock of roads and highways railway harbors and maritime	Spanish provincial level	Output elasticity: 0.029-0.049 (direct effect); output elasticity: -0.108 to -0.106; (spillover effect)

	signaling		
Ozbay et al. (2007)	Street and highway investments	18 counties in New York/New Jersey	Output elasticity: 0.135-0.206; spillover effects tend to decrease when the distance increases from the investment location
Khadaroo and Seetanah (2008)	Transport capital investment	Mauritius (a small island)	Short-run output elasticity: 0.145; long-run output elasticity: 0.263
Sloboda and Yao (2008)	Public spending on transportation	US state level	Public spending on transportation: -0.016; interstate spillovers of transport expenditure: -0.107
Hong, Chu and Wang (2011)	Comprehensive index based on quantity and quality of railway, roadway, airport, seaport	Chinese provincial level	The output elasticity of highway infrastructure on economic growth: land transport (including roadway and railway): 0.554-2.757; water transport: -9.015 to 0.938; air transport: -0.427
Jiwattanakulpaisarn et al. (2011)	Density of highway lane miles	US state level	The output elasticity: own-state highways: 0.03; own-state and adjacent states' highways: 0.037; own-state and all other states' highways: 0.054
Jiwattanakulpaisarn et al. (2012)	Density of highway	US state level	Long-run output elasticity: all roads: 0.035-0.039
Zhang (2013)	Transport infrastructure capital stock	Chinese provincial level	The total output elasticity of transport infrastructure: 0.05-0.07
Tong et al. (2013)	Road disbursement, rail mileage	US state level	Output elasticity of road: 0.02-0.03 (direct effect); 0.24 (spillover effect)

Note: This figure is based on Deng, T. (2013) "Impacts of Transport Infrastructure on Productivity and Economic Growth: Recent Advances and Research Challenges."

Another unsettled question for transport-led growth hypothesis is the **distributional effects of transport networks**, which could provide important implications for regional disparity. Changes in accessibility (due to the decreasing transportation cost) may induce relocation of economic activities, which leads to more economic growth in one place at the expense of less growth or even decline in another (Vickerman et al., 1996; Boarnet and Haughwout, 2000; Ottaviano, 2008; Banister, 2012). On the one hand, for fixed factor endowments, the increased access to markets and ideas should benefit all regions. On the other hand, transportation infrastructure increases the access of rural regions to cities, and the well-known agglomeration effects of cities may cause productive capital and skilled labour to move from periphery regions to core cities over time, with the result that those who remain in periphery areas receive very limited benefits from urbanization or even become impoverished. Thus a greater understanding of these distributional effects is essential given that balancing the spatial distribution of economic development resulting from transport facilities development is often a major rationale for investment decisions (Chandra and Thompson, 2000; Holl, 2004; Banerjee et al., 2013; Roberts et al., 2012). Much of the evidence for the existence of such a distributive effect has been obtained from developed countries in recent years, such as Spain (Holl, 2004a, 2007; Lopez et al., 2008), Portugal (Teixeira, 2006; Holl, 2004b), the Netherlands (Meijers et al., 2012; Louw et al., 2013) and the US (Funderburg et al., 2010). However, to our knowledge, there have been very few empirical studies investigating this distributive effect of transport infrastructure in China, despite China having invested heavily in its transport facilities in recent years.

1.4.2. Education-economy nexus

While the neoclassical growth theories have incorporated education as an important input to growth, empirical evidence is still far from unanimous and conclusive. Early attempts in this research field tended to confirm economists' traditionally optimistic views regarding the macroeconomic payoff to investment in education (Landau (1983), Baumol et al (1989), Barro (1991) and Mankiw, Romer and Weil (1992). They found that a variety of educational indicators have the expected positive effect on output growth. During the second half of the nineties, however, a new round of empirical papers produced rather disappointing results on the effects of education on aggregate productivity (Benhabib and Spiegel, 1994; Islam, 1995; Caselli, Esquivel and Lefort, 1996; Pritchett, 2001). The Australian Workforce and Productivity Agency (2013) provided a good literature review on the link between education and growth, discussing the association between education (human capital) and productivity for individuals, firms and the economy as a whole.

The mixed empirical evidence may be due to many possible factors. For example, the distribution of education is often neglected in education investment planning and public policies. However, given the amount of investment in education, who gets educated matters a great deal (Lopez et al., 1999). The distribution of educational resources may also explain the regional variance in growth as well as the level of education attainment itself. Education cannot be fully traded on the free market as physical capital, thus the market mechanism cannot guarantee that education investments for different people generate equal marginal returns (Park, 2006). In that case, the aggregate production function depends on the distribution of education (equality in educational attainment) as well as on average educational attainment itself. Realizing this, some scholars have tried to explore the link between educational distribution and growth. Table 1-5 describes recent studies on estimation of growth impact of education attainment and its distribution.

Table 1-5. Recent studies on estimation of growth impact of education attainment and its distribution

Authors	Education/ education distribution indicators	Data	Findings
Lopez, Thomas and Wang (1999)	Total mean years of education; standard deviation of education	Panel data from 12 Asian and Latin American countries for 1970 to 1994	Increases in the stock of human capital tend to accelerate growth; Unequal distribution of education tends to have a negative impact on per capita income in most countries
Thomas et al. (2001)	Labor force's average years of schooling; education Gini index	85 countries 1960-1990	Increased in per capita GDP is positively related to the education attainment level while negatively associated with education inequality
Castello and Domenech (2002)	Average years of schooling years; school attainment levels by quintiles/human capital Gini coefficient	116 countries over five-year intervals from 1960 to 1990	Positive effect of human capital on economic growth; Negative effect of human capital inequality on economic growth
Hassan and Shahzad (2005)	No enrollment ratios/the average schooling years; the standard deviation of education/ educational Gini index	National data of Pakistan for 1973-1998	Education provision has a very strong impact both on educational inequality and on the rate of economic growth
Park (2006)	Educational attainment levels; the variance of schooling years in the population	Pooled 5-year interval time-series data set of 94 developed and developing countries for 1960–1995	Dispersion index as well as average index of human capital positively influences productivity growth
Schwerdt and Turunen (2007)	Quality-adjusted index of labour input	Euro area covering the period 1983-2004	Significant and increasing role for changes in labour quality in explaining labour

			productivity growth
Digdowiseiso (2009)	Average years of schooling; standard deviations of education	Indonesia, 1996-2005	Higher level of human capital (AYS) and the relative dispersion of human capital have a disequalising effect on the income distribution
Castelló-Climent (2010)	Human capital Gini coefficient; the distribution of education by quintiles attainment levels and the average schooling years	108 countries during the period 1960–2000	Different effect of inequality on growth depending on the level of development of the region
Rodriguez-Pose and Tselios (2010)	Average in education level completed; inequality in education level completed (Theil index)	Regionally aggregated microeconomic data for more than 100,000 individuals over a period of 6 years	Educational achievement is positively correlated with economic growth; educational inequality has a significant positive association with subsequent economic growth
Gungor (2010)	Educational attainment levels of the labor force; education Gini coefficients	Provinces of Turkey in the period 1975-2000	Positive link between education attainment level and growth; a non-linear relationship between growth and education inequality
Barro and Lee (2010)	Overall years of schooling	146 countries from 1950 to 2010	Schooling has a significantly positive effect on output
Fleisher et al. (2010)	Average schooling years	Chinese provincial data	Education positively affects output and productivity growth; both direct and indirect effects of educational on TFP growth
Castello (2011)	Human capital Gini index	Cross-section of countries over the period 1960-2000	Negative effect of human capital inequality on economic growth, which is reinforced in countries with less developed financial systems

It seems that the vast majority of recent empirical studies indicate that education investment has made a positive contribution to productivity and economic growth, however the education distribution-growth link appears to be uncertain. The impression emerging from the initial empirical studies is that inequality is negatively associated with growth (Birdsall and Londono, 1997; Lopez et al., 1999; Thomas et al., 2001; Castello and Domenech, 2002), suggesting a decreasing inequality in educational attainment with a higher economic growth and vice versa. However, this negative inequality-growth nexus argument has been challenged in other studies, suggesting an uncertain relationship between inequality and growth, and even positive association in several developed countries (Rehme, 2007; Rodriguez-Pose and Tselios, 2010; Castello, 2010a). Recent literature also identifies a robust non-linear link between inequality in education and economic development (Gungor, 2010; Wai et al., 2012). Altogether, there is no consistent conclusion on this topic, and **very limited implications for the emerging economies like China**.

Moreover, many studies have examined the impact of education on China's economic growth, while mixed results are observed (Fleisher and Chen, 1997; Weil and Hao, 2011; Fleisher et al. 2010). Most studies find a positive and significant impact of education on China's growth rate (Fleisher and Chen, 1997; Fleisher et al. 2010), while several research results show insignificant effects (Wei et al., 2001). In short, the different evaluations lead to diverging conclusions, while none of them directly states **the role of education attainment and its distribution in explaining China's growth and regional disparity**.

This research project attempts to fill the above gaps in the literature. We try to contribute to exploring the role of public infrastructure (both transport equipment and education) in China's development, focusing on the causal relationship and revealing the 'real' growth impact of public infrastructure investment. The findings from this research project are expected to shed more light on the infrastructure-led growth hypothesis and also provide important policy recommendations for China.

1.5. Research questions

Based on what we have discussed in the preceding sections, the main research question of this book is:

How does (investment in) public infrastructure contribute to economic growth in China? And how does it affect the (growing) regional disparity?

The main research question leads to a series of theoretical and empirical sub-questions including:

1a. Is the (growing) regional disparity in economic development within China related to existing spatial inequalities in the distribution of transport and/or education infrastructure?

1b. Can we find a statistically significant association between regional differences in public infrastructure endowments and regional levels of (real) per capita income in China?

1c. What are the patterns of (Granger-) causality between spatial disparities in public infrastructure and spatial economic development in China and how the causality change across regions?

2a. What is the impact of transport infrastructure on China's economic growth?

2b. What is the impact of transport infrastructure investment on economic growth in China's Eastern, Central and Western Regions?

2c. Does the regional allocation of transport infrastructure investment help to reduce regional inequalities in economic development?

3a. Does educational attainment and its distribution matter for regional growth in China?

3b. Is this inequality in education at lower levels of economic development more impactful on economic growth than at higher levels of development?

3c. If so, what does this mean for China and its regions?

4a. Do falling transportation costs, due to significant transport investments throughout Chinese cities, lead to a rising agglomeration of economic activities in core areas?

4b. What is the impact of regional differences in public investment in education on the regional concentration of economic growth?

4c. Do transport investments and educational investments have a similar impact on regional economic growth patterns?

4d. How do they work out differently? And why?

1.6. Book outline

The structure of the book is as follows:

The regional distribution pattern of the public infrastructure and economic development in China is introduced, the problem of infrastructure-led growth and disparity is diagnosed, and the research question is posed. China has witnessed dramatic economic development during the post-reform period. However, China's transition to a market-based economy has created new problems, among which is the growing regional inequality in per capita income. Both theoretical and empirical evidence is provided to support the public infrastructure-led growth hypothesis, it is questionable, however, whether investment in infrastructure has been helpful in spurring economy, and in reducing the growing coastal-interior gap in

China, considering that plenty of large infrastructure projects have been constructed or planned in the less-developed interiors. Therefore, our research question reads: Could investment in infrastructure explain the economic growth and increasing regional disparity in China? (Chapter 1)

The causal linkages between transport infrastructure and economic growth in China are determined at national and regional levels separately. Chapter 2 describes the similar distribution pattern of transport infrastructure and economic activities in China, which present a good opportunity for examining the causality between transport infrastructure endowments and regional growth performance in China. We examine causality in a panel cointegration and a Granger causality framework using time series data throughout the 1978–2008 period at the national and regional level in China. The intent of our regional level analysis is to obtain insight into possible variations in the direction of causality (or lack of causality) between transport investment and economic growth at the regional level and into how our regional findings compare to the findings at the national level. Additionally, if such causality can be determined at the regional level, it would be useful to explore whether the regional disparity of economic performance can be reduced through enhancing transport investment in the poor areas of China. (Chapter 2)

The impacts of transport infrastructure on economic growth in Chinese regions are explored. After identifying the causality between transport infrastructure and economic development, we try to estimate the impact of transport stock on overall economic growth, and on growth at the regional level using panel data for a sample of 28 provinces and municipalities over the period 1978–2008. The findings from this empirical study could help identify whether there is variation in the productivity effects of transport capital stock across sub-national areas, which is valuable for policymaking in view of the considerable disparity among the three Chinese regions. (Chapter 3)

The long-run effects of education attainment and its distribution on China's growth in China are estimated. In order to answer the research questions, this empirical study will analyze the distribution of education in China measured by the educational Gini index, and empirically explore the correlation between educational attainment, inequality and economic growth using heterogeneous panel cointegration techniques. This empirical study will identify whether education attainment and its distribution matter for regional growth in China, and whether this inequality is more relevant for growth than educational endowments. This research will reside in a new effort to address the relevance of inequality in education distribution for China's economic performance and regional disparity, which may have important implications for education investment policy. (Chapter 4)

The distributive impact of public infrastructure (both transport infrastructure and education) is examined. Using panel data from 274 Chinese municipalities in the 2000–2010 period, this study explores the role of transport network and education in the evolution of China's economic geography. In doing so, our study relates to how, and how much, transport infrastructure contributes to the agglomeration and dispersion of economic activities across Chinese regions. Meanwhile, we take education (facilitate the transportation of ideas) as a comparative variable to highlight the role of road infrastructure (facilitate the transportation of goods) in narrowing China's spatial concentration and inequity. The results from this study may be very meaningful for infrastructure investment policy design. (Chapter 5)

A synthetic answer to the research question is formulated, based on all theoretical and empirical study in the previous chapters. In the concluding chapter, we systematically answer the sub-questions, synthesizing our findings both at theoretical and empirical levels. In answering the main question, our research indicates that transport infrastructure may bring economic growth but is also the cause of regional growing disparity. Alternatively, education could provide both growth and equality. These lessons and discoveries provide helpful signposts and dispel a number of lingering confusions about the relationship between public infrastructure and the economy. Based on our findings, we make several policy recommendations to Chinese governments for a public infrastructure investment plan. And finally we present our research limitations, reflections, and future research agenda. (Chapter 6)

Chapter 2

Causal relationship between transport infrastructure and economic growth in China[5]

2.1. Introduction

In three decades of market-oriented reforms, China has been one of the world's fastest-growing economies, the national GDP of which grew by more than 9% per year from 1985 to 2009 (OECD,2010). However, accompanying the rapid economic growth is aggravated inequality among different regions. All the Chinese provinces are divided into three groups according to the definition provided by State Statistical Bureau (SSB) of China, as shown in Figure 1-8 in Chapter 1. China has long pursued a biased development policy with

[5] This chapter is a slight adaption of Yu, de Jong, and Storm (2012), published with the following title: Transport infrastructure, spatial clusters and regional economic growth in China.

the largest portion of public investment being concentrated in the eastern coastal provinces. Therefore, it is not surprising that regional disparity of China has increased significantly since the economic reform: the difference in economic growth rates between eastern China and western China was as high as 5 percentage points during the past three decades (SSB, 2009). From this perspective, reducing the economic gaps between regions is necessary either through appropriate financial policies of Chinese government directly, or by facilitating growth spillovers from rapidly developing coastal regions to backward inland provinces indirectly (Demurger, 2001). Recently, more and more attention has been paid to the poor western regions as a result of the growing concern about the social instability accompanied by the increasing differences in interprovincial economic welfare (Chen, 2010). However, how to validly reduce China's interprovincial economic disparity is still unclear for the Chinese central government (Fleisher et al., 2010; Tan and Yang, 2009). Considering China's huge size, important regional differences arise naturally in geography and in natural resource endowments, which may have a substantial impact on regional economic disparity. To compensate for these natural constraints, the availability of an appropriate transport infrastructure might prove helpful in facilitating communications between provinces and with the outside world (Demurger, 1999). Thus, improved transport infrastructure is said to be a critical factor in the path of economic growth and urbanization for Chinese provinces (Zhang, 2008). Understanding the policy implications of the linkage between transport infrastructure and regional economic growth is of particular importance because China's rapid economic growth, urbanization and sustainable development have placed a great strain on its transport infrastructure systems. Much still needs to be understood about the causal interactions of the two variables in order for the Chinese officials to make the right decisions. An appropriate planning of transport infrastructure investment can affect the growth potential of Chinese cities, and also help to decline regional disparities probably in order to get a sustainable economic growth and maintain social stability.

Perhaps surprisingly, available empirical findings on the impacts of transport infrastructure are inconclusive. From Aschauer's (1989) original paper, in which he argues that public investment in infrastructure is quite productive, a rich body of research has contributed to the establishment of a statistical linkage between infrastructure and economic growth. The main findings from these studies concern the output elasticity of infrastructure capital (Munnell, 1992; World Bank, 1994; Holtz-Eakin and Schwartz, 1995; Calderon and Serven, 2003; Canning and Bennathan, 2007; Crafts, 2009; Sahoo and Dash, 2009), and most of them find a positive output elasticity of infrastructure investment though comparatively lower than Aschauer's. Another focus in the literature is on optimal and efficient use of infrastructure for economic growth. Canning and Pedroni (2004) emphasize that there is an optimal level of infrastructure maximizing the growth rate and anything above would divert investment from more productive resources, thereby reducing overall growth. The findings from these empirical studies are sharply different and shed little light on causal mechanisms linking infrastructure and the economy (Lakshmanan, 2011). Studies on the topic of the causal linkage between transport infrastructure and economic growth are few, and most of them are at the state level. Banister and Berechman (2001) discuss the relationship between transport investment and economic growth from a theoretical point of view. Buurman and Rietveld (1999) analyse this issue in terms of demand and supply and indicate that transport infrastructure affects economic growth through both short-run and long-run effects. Fernandes and Pacheco (2010) examine the causality between economic growth and domestic air passenger transport in Brazil using Granger causality tests at the national level and find that there is a unidirectional Granger causal relationship from economic growth to domestic air transport demand in Brazil. Bose and Haque (2005) provide an explanation for the consistent relationship between public investment in transport and communication and economic growth for a group of developing counties and find that the strong association is the result of the effect running from growth to public investment rather than vice versa. Rietveld and Nijkamp (2000) investigate the relationship between transport infrastructure and economic growth separately at the local, regional and national levels and conclude that transport infrastructure has a significant impact on regional economic growth.

In the case of China, most empirical studies have focused on finding the causal relationship between China's transport infrastructure development and economic growth at the national level (Gao, 2005; Zhang and Sun, 2008; Tan and Yang, 2009). It seems that the scholars hold different views on the existence and direction of causality in this context. They obtain very different, even conflicting, results due to the various methods and indicators in tests. At the national level, Zhang and Sun (2008) find a one-way Granger causality from economic growth to transport investment, while Tan and Yang (2009) find bidirectional causality. Li (2008) investigates the relationship between China's railway transportation industry and national economic growth using cointegration theory and the Granger causality test and concludes that there is a unidirectional causality from railway cargo to national economic growth. Sahoo et al. (2010) examine the role of infrastructure (including transport infrastructure) in promoting economic growth in China for the period 1975–2007 and find a unidirectional causality from infrastructure development to output growth for the nation. There are no studies on the causal relationship between China's transport infrastructure development and economic growth at the sub-national level until now. That is why we propose a new examination of this issue by employing the panel data of 31 Chinese provinces over the 1978–2008 period. The intent of our regional level analysis is to obtain insight into possible variations in the direction of causality (or lack of causality) between infrastructure investment and economic growth at the regional level and into how our regional findings compare to the findings at the national level. Additionally, if such causality can be determined at the regional level, it would be useful to explore whether the regional disparity of economic performance can be reduced through enhancing transport investment in the poor areas of China.

Our study will address these questions:

What are the mechanisms linking transport improvements and the economy?

Is there a causal relationship between them in China and if so, what is its direction?

Does the causality between transport investment and the economy vary across regions?

To answer these questions, the paper provides both theoretical analysis and empirical evidence on the linkages between transport infrastructure endowments and regional growth performances. The main methodological contribution of this paper is the use of the panel unit root, panel cointegration and Granger causality approach, which has not been used before in the literatures on the causality between China's transport investment and economic growth at a regional level.

The rest of the paper proceeds as follows. Section 2-2 gives an overview of economic growth disparity and the evolution of infrastructure availability at both the national and regional levels. Section 2-3 analyzes the mechanisms linking transport infrastructure and economic growth from a theoretical viewpoint. Section 2-4 provides an empirical test of the causal relationship between economic growth and transport infrastructure development using panel unit root test, panel cointegration test and Granger Causality test at both national and regional level. Section 2-5 concludes with several transport infrastructure investment policy related remarks.

2.2. Transport infrastructure distribution and regional economic growth in China

2.2.1 A regional pattern in China's economic growth: spatial clusters

China has experienced growing across-regional inequality since 1978, the start of reform and opening-up policy, especially after the financial decentralization in 1994. From the beginning of the 1980s, growth disparity across major regions remained stable, but it rose sharply since the early 1990s (See Figure 2-1). The issue of the rising disparity among Chinese regions has received much attention in recent years. The indicator of the ratio of GDP *per capita*[6] between the wealthiest and poorest region may illustrate the situation. In the year 2009, the ratio of real per-capita GDP between the wealthiest and the poorest province was 8.65 in China (OECD, 2010). By comparison, among the major regions of the United States in 2009, the ratio of the highest to lowest regional per-capita GDP was only 1.3 (United States Bureau of Economic Analysis, 2010). In India for 2009, where is also a typical developing country with huge population, the comparable ratio (in nominal terms) was only 4.5 (Wu, 2009).

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[6] In the discussion of Chinese economic development, we choose GDP per capita as an indicator of development. We are aware that GDP per capita as a development indicator has serious limitations because it does not count income inequality, is not (always) correlated with well-being and is not strongly correlated with social indicators (including gender equality, access to education and health). However, alternative measures such as the human development index are not available on a longitudinal as well as regional basis. Therefore, we work here with GDP per capita as an imperfect but still meaningful development indicator to explain Chinese economic phenomena in this paper

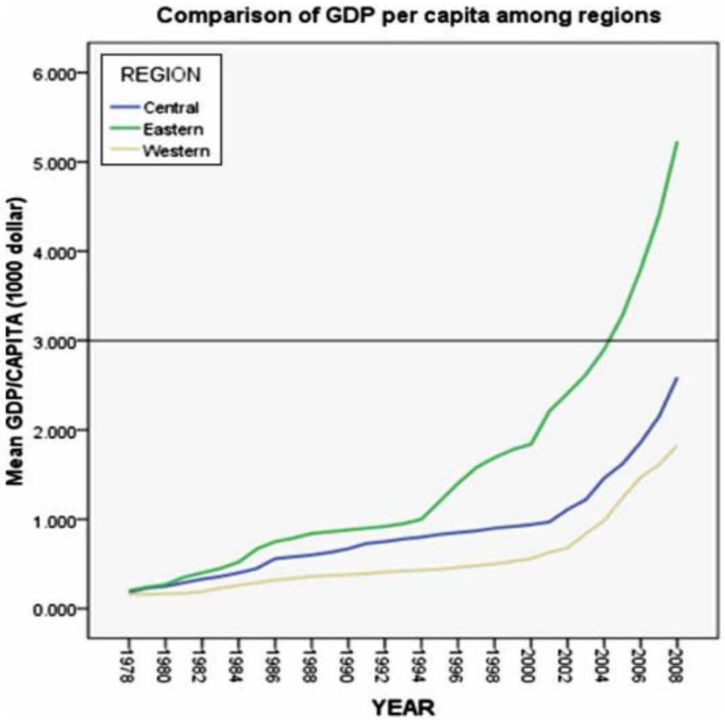

Figure 2-1. Comparison of GDP per capita among regions

Besides the various geographic and environmental conditions, China has long executed a biased development policy, "Coastal Priority Development Strategy", proposed by Deng Xiaoping in the early of the economic reform. According the official regional classification, most provinces in the Eastern region, located near the coast, have been leading in economic growth in China for a long time. Meanwhile in the Western region, most provinces have suffered from drought, difficult climatic conditions and having uninhabitable mountainous areas, lagging far behind in economic growth and living conditions. Since 1998, the Chinese government has done a great effort to develop western regions through financial policies, such as the "Western development Strategy", but the economic benefits have remained far more modest than expected (Zhou, 2009). The Chinese government may hope to see the rapid growth of the coastal provinces helping spur the development of the central and western regions. Nevertheless, indeed, there is little impact on the inland regions, even though most coastal provinces have witnessed a favorable development. As a result, the western provinces such as Gansu, Xinjiang and Tibet remained far behind in terms of GDP per capita in the early 2000s, while most coastal provinces had caught up with the richest municipalities, such as Beijing and Shanghai (Demurger, 2001). The gap between the central region and coastal region also grew larger due to the neglect of Chinese government to the central part since the economic reform. Consequently, due to growth concentration along the coast, the most pronounced disparities have dramatically grown between coastal and inland provinces in China.

As Figure 2-2 shows, there are two clear features in the regional distribution of China's economic growth:

First, China's economic activities mainly focus on the eastern coastal region. In terms of GDP per capita in provincial level, we can rank the provinces and find their relative positions. The top 7 are Shanghai, Beijing, Tianjin, Jiangsu, Zhejiang, Shandong and Guangdong. All these provinces are located on the East Coast. The Yangtze River Delta, the Pearl River and the Bohai Baky Region have been the clustering regions for Chinese economic activity for a long time.

Second, the clusters of economic activities are like stair steps decreasing from the higher eastern China to the lower western China. It means that there are identical gaps among the economy of the eastern, central and western China. With respect of GDP per capita, the bottom 5 are Tibet, Qinghai, Xinjiang, Sichuan and Gansu, all of which are located in western China.

Figure 2-2. GDP per capita at a provincial level in 2008

Note: First group area, over $3000; second group area, $1500–3000; third group area,$1200–1500; fourth group area, less than $1200. All the data are calculated by the authors based on the China Statistical Yearbook 2009. Available at: http://www.stats.gov.cn/tjsj/.

2.2.2 National trends in transport infrastructure investment

According to China's large scale, transport infrastructure is particularly important since industrial activities tend to be located far from raw materials. Take energy resources as an example: China's natural gas and coal, which are located in the central and western provinces, such as Shanxi and Guizhou, while Chinese industrial centers are mainly based on the coastal region. As the industrial centers need more and more energy resources for their development, a weak transport infrastructure network across regions may lead serious inefficiency in the transport of energy resources, as well as a potential increase in energy's price (Demurger, 2001). At the same time, transport infrastructure is essential for easy commuting from work to home. Hence, the Chinese government has paid much attention to the construction of its transport infrastructure since the establishment of PRC in 1949.

During the pre-reform period, the centralized decision-making structure applied to all kinds of investments, including those in infrastructure construction. In the 1960s, centralization implied that infrastructure investments were made to favor heavy industry, which had a particular influence on infrastructure equipment, especially transport facilities. The development of the transport network received most emphasis in North-Eastern China, such as Jilin, Heilongjiang and Liaoning, the heart of heavy industry. More specifically, railway development was favored over other types of transport, to carry huge quantities of raw material and resources at a lower cost from resource-rich provinces, such as Shanxi, to industrializing Northern provinces.

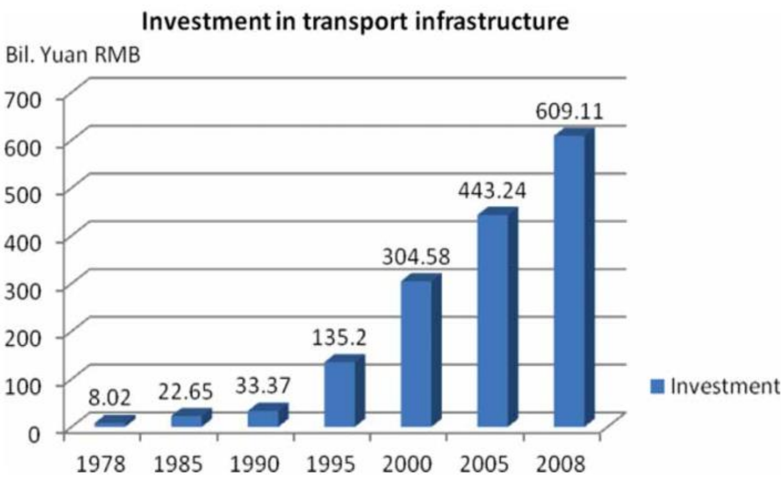

Figure 2-3. Investment trends in transport infrastructure in China

Since the economic reforms began in 1978, and especially since the fiscal decentralization in 1990s, there has been a significant increase of the investment in various types of transport infrastructure, especially in roads. Both the central government and the local governments preferred to construct transport infrastructure in order to attract FDI and investment from national state-owned enterprises. As Figure 2-3 shows, investment from governments at different levels in fixed transport infrastructure assets was RMB 609.11 billion (about 91 billion US dollar) in 2008, 96 times the size of the year 1978.

Figure 2-4 describes the trends in economic growth, transport infrastructure investment growth, and freight traffic density growth since 1978. From the figure we can tell that the growth rate in transport infrastructure investment's growth rate has surpassed GDP's growth rate since 1994. Investment in transport infrastructure in 2008 is about 80 times the size of the year 1978, while GDP increased by 50 times during the same period.

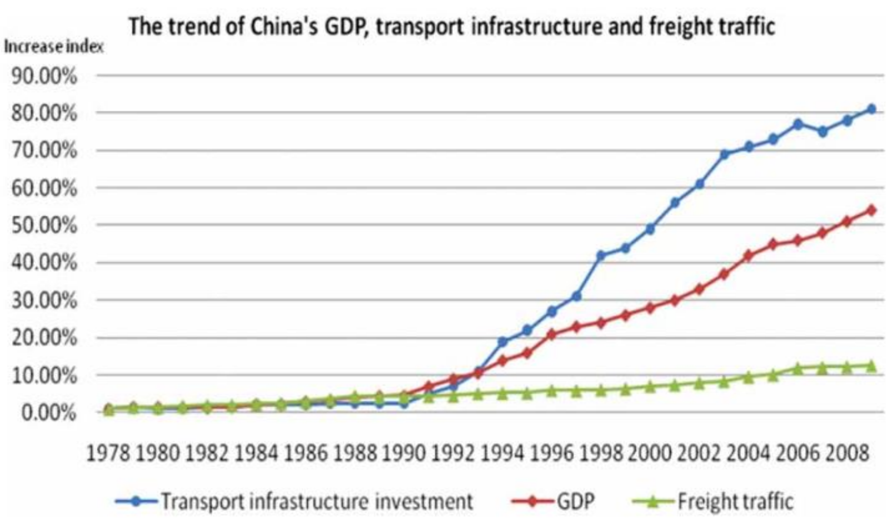

Figure 2-4. The trends of China's GDP, transport infrastructure and freight traffic density

Investment in transport infrastructure accounted for less than 1.79% of GDP in 1978, however this ratio has increased to 5.64% in 2009; meanwhile, the proportion of transport infrastructure investment in national public infrastructure investment increased to 42% in 2009 from 23% in 1978 (Wu, 2009). These data clearly indicate that Chinese government has begun to emphasize investment in infrastructure, especially in transport infrastructure, which relieved many transport "bottle-necks" in China. Nevertheless, comparing with developed countries, the proportion of transport infrastructure investment in GDP is 5.64% in 2009, still very low, while the proportion of America in the same year is 9.90%[7].

To conclude, China has achieved tremendous progress in its transport infrastructure construction since governments at different levels made huge investment in it. In the 1980s and early 1990s, the Chinese people still relied on traveling by shabby and nasty trains and experienced enormous difficulty in buying train tickets (Zhang et al., 2007). Nowadays, more and more cities are connected through high-speed railroads and millions of people travel on comfortable motorways every day.

2.2.3 Spatial distribution of transport infrastructure

Apart from differential natural geographical conditions, China's transport infrastructure construction has experienced growing interprovincial inequality since its economic reform. The region-biased policy has driven the largest portion of public investment to the coastal eastern regions (Yang, 1990; Tang, 1993; Wei, 1999). In the early 1990s, the Chinese government realized the accruing disparity among regions and they chose to give the priority

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[7] The data are collected from the newspaper Economy of the 21st Century (translation from the Chinese).

to develop the transport infrastructure with both economic and political purpose. “Western Development Strategy” was carried out in 1998, which brought the transport infrastructure standards of the western provinces to a higher level, but still very low compared with coastal provinces (Wu, 2009; Tan and Yang, 2009). In spite of these efforts, the economy in the western provinces did not grow as significantly as people expected. The gap between the eastern and western region is not narrowing, but indeed constantly widening. Compared with the western region, the central region enjoys a better geographical position since it is the connection plane of the other two regions, but this fact seems to have played only a minor role in the transport infrastructure investment policies. Thus transport infrastructure development in central provinces was relatively slow.

As to railways, in 2008 the five regions with highest railway density are Beijing, Tianjin, Shanghai, Jiangsu and Henan, which are all located in the eastern China except Henan province. Among the top 10 regions with highest railway density, there are seven from the eastern part, three from central China and none from western China. However, in the 10 regions with the lowest railway density, eight are in the western area and the other two are in the central area. Beijing's density, 68.94 km/1000 km^2, is the highest, while Tibet has the lowest, 0.56km/1000 km^2. Xinjiang has the second lowest railway density, 1.98km/1000 km^2. Considering the average density, the eastern part is 22.14km/1000 km^2; the middle part is 16.34km/1000 km^2; the western part is 4.62 km/1000 km^2. The average density of the eastern part is four times that of the western region. The national average density is 8.71 km/1000 km^2, which is almost two times that of the western part.

Regarding motorways, in 2008 the top five provinces and municipalities with highest highway density are Shanghai, Zhejiang, Shandong, Jiangsu and Beijing, all of which are located in the East. Shanghai has the highest highway density, about 1679.26 km/1000 km^2 and Tibet has the lowest density, about 41.53 km/ 1000 km^2. The highway density is 970.162, 552.45 and 202.90 km/ 1000 km^2 for eastern region, the central region and the western region, respectively. The highway density of the eastern region is almost 5 times that of the western region[8]. China's economic activities mainly concentrate on the coastal provinces, thus it's not surprising that the highway density of eastern region is much greater that the ones in the central and western regions.

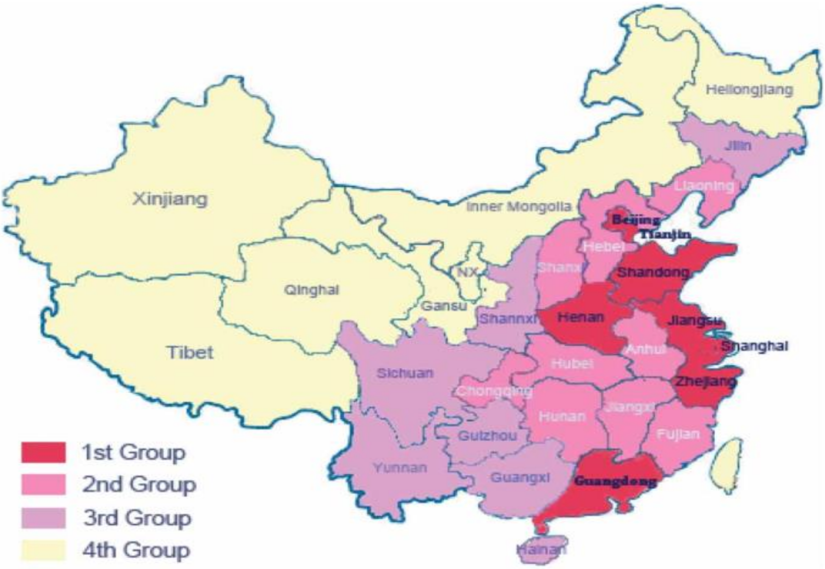

Figure 2-5. Average transport network density at a provincial level in 2008

Note: Including railways, highways and inland waterways (km/1000 km^2). First group area, over 1400; second group area, 800–1400; third group area, 500–800; fourth group area, less than 500.

Including all types of transport infrastructure, Figure 2-5 shows that, most provinces in 1st Group that are relatively well endowed are located in coastal provinces. In contra distinction, transport network

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[8] All the figures in Section 2.3 are calculated by the author based on the data collected from SSB of China and Ministry of Transportation (1984–2009)

density remains very low in remote provinces, which nonetheless have vast energy resources, such as Ningxia, Inner Mongolia, or Xinjiang.

Besides the regional quantity disparity of transport infrastructure, the quality is also unequally distributed among different regions. According to their level and quality, roads are classified into six classes from high to low, as defined by 'Technical Standard of Highway Engineering in China (File No. JTJ001-1997)'[9]. Figure 2-6 shows the shares of different class roads among the three regions. Apparently, the western region is poorly served by roads of high class compared to the coastal, and even to the central, region.

Consequently, we can draw the following conclusion: there is a wide difference both in quantity and quality of transport infrastructure among regions, which clearly appears as stair steps decreasing gradually from eastern China to western China. Transport infrastructure's distribution has an apparent feature of spatial agglomeration.

Based on the analysis above, we observe that transport development and general economic development proceed together in China. Is it transport investment that promotes economic development, or economic development that creates demand for more transport services? We will examine if there is a causal relationship between transport infrastructure development and regional economic growth and whether the causality varies across regions.

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[9] Highway: average daily volume is 25 000–100 000 cars. Class roads include four classes according to their average daily volume. Class 1: average daily volume is 15 000–55 000 cars; class 2: average daily volume is 3000–7500 medium-duty trucks; class 3: average daily volume is 1000–4000 medium-duty trucks; class 4: average daily volume is 200–1500 medium-duty trucks; substandard: average daily volume is less than 200 medium-duty trucks.

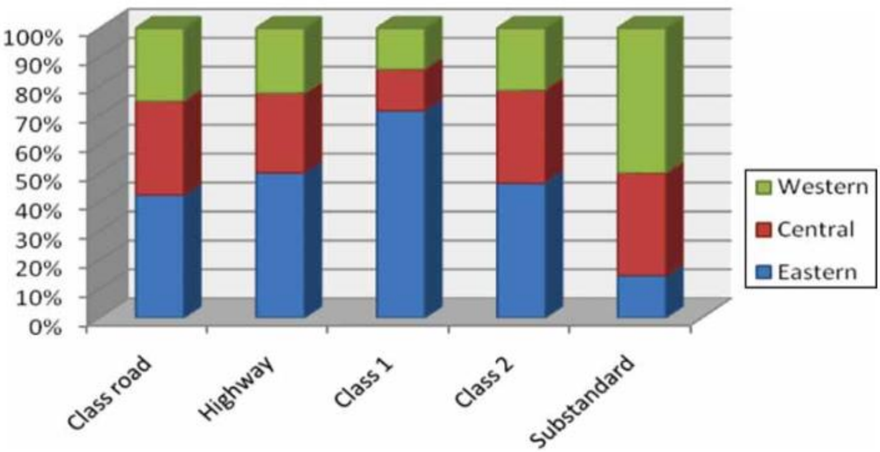

Figure 2-6. Quality disparity of road infrastructure between regions

2.3. Causal linkages between transport improvement and the regional economy

In theory, provision of transport infrastructure is hypothesized to affect regional economic growth by lower transport costs and greater accessibility. Macroeconomics can help explain whether and to what degree transport infrastructure can lower production costs and increase the level of economic output (Samuelson, 1954; Fujita, 1989; Krugman, 1991; Lafourcade, 2009). Meanwhile, there are a variety of opinions among decision-makers and economists as to the causal mechanisms between transport infrastructure improvements and output and productivity enhancements (Fujita et al., 1999; Zhang and Sun, 2008; Lakshmanan, 2010). In this section, the causal linkages between transport improvement and regional economy will be highlighted in order to determine whether it is possible to establish the causality between them.

2.3.1 How does transport infrastructure investment affect economic growth?

Economic growth is achieved with the money and time savings induced by transport infrastructure improvement and this mechanism is experienced at the regional level by governments or enterprises in various types of markets (McCann, 2005; Ottaviano and Puga, 1997; Ottaviano and Thisse, 2002). What drives the location of firms and consumers is the accessibility to spatially dispersed markets, which has been recognized for long both in spatial economics and regional science (Fujita and Thisse, 2002). The lower transport costs and greater accessibility for transport-using production sectors and firms translating goods from firms to retailers, and for households engaged in commuting probably lead to the following consequences: higher efficiencies caused by scale economies, spatial agglomeration economies, market expansion and restructuring, innovation benefits in spatial clusters, etc. Indeed, the accruing evidence of these economic mechanisms has been analyzed and reported in the study of railways and highways in many countries in recent literature (Rephann and Isserman, 1994; Surico, 2001; Lakshmanan, 2010).

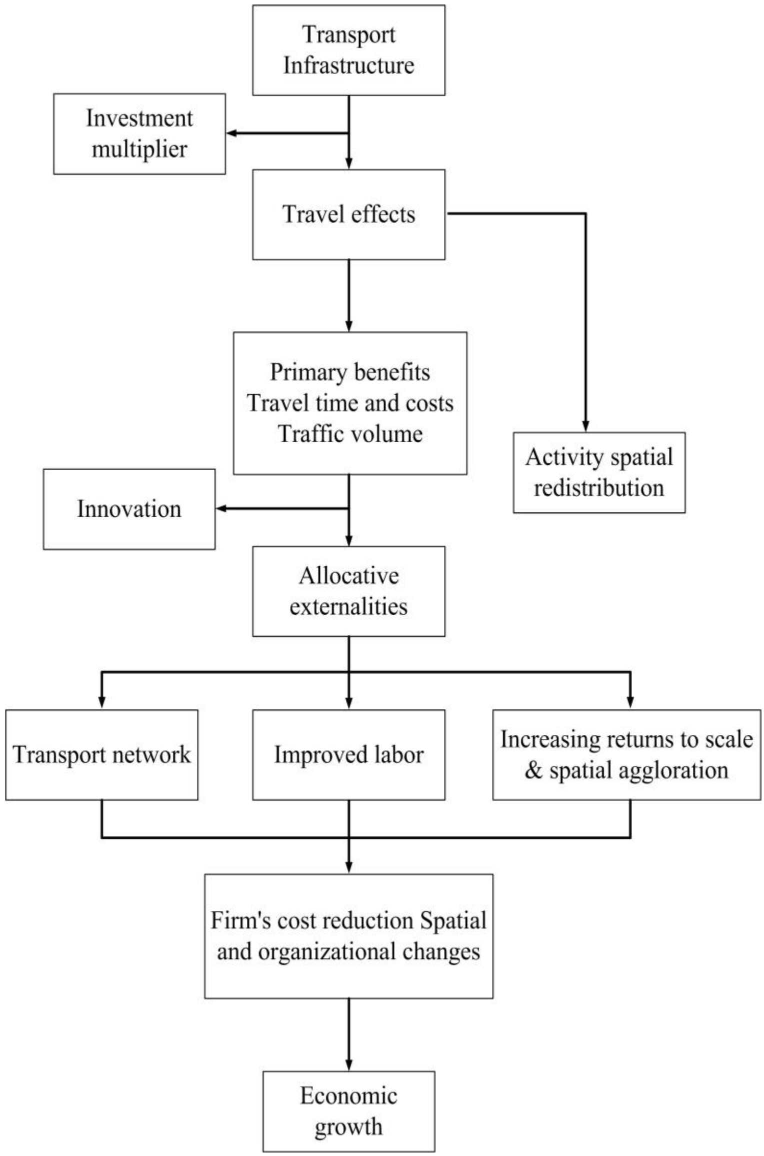

Figure 2-7. Interaction Mechanism of Transport infrastructure investment on economic growth

Note: This figure sourced from Banister and Berechman (2001).

Figure 2-7 offers one view of the mechanisms and processes underlying the economic benefits of transport infrastructure investments. In the short term, transport infrastructure investment could bring plenty of job opportunities and new blood for the construction enterprises. Meanwhile, as an input of capital flow, infrastructure investment doesn't have the character of a public good when the investment still does not become capital stock. In such cases, infrastructure investment would affect economic growth through a multiplier effect. In the long term, the investment amplifies the scale and stock of transport infrastructure. The increasing scale of stock can significantly improve regional accessibility, shorten the spatial distance between regions and fasten the movement of production factors. The lowered costs and increased accessibility brought by transport infrastructure are supposed to modify the marginal costs of shipping-goods producers, the households' mobility and demand for goods and services. Then the benefits of "transport network economics", "improved labor supply" and "increasing returns to scale and spatial agglomeration effects" can be realized, as shown in Figure 2-7. That's the mechanism linking transport improvement and economic growth in long run.

2.3.2 Economic development's feedback to transport infrastructure

Compared with mechanisms of how the transport infrastructure investment affects economic growth, the interaction of how economic development works on transport infrastructure seems much easier. The obvious fact is that, economic growth provides necessary financial and technical support to transport infrastructure investment and its improvement.

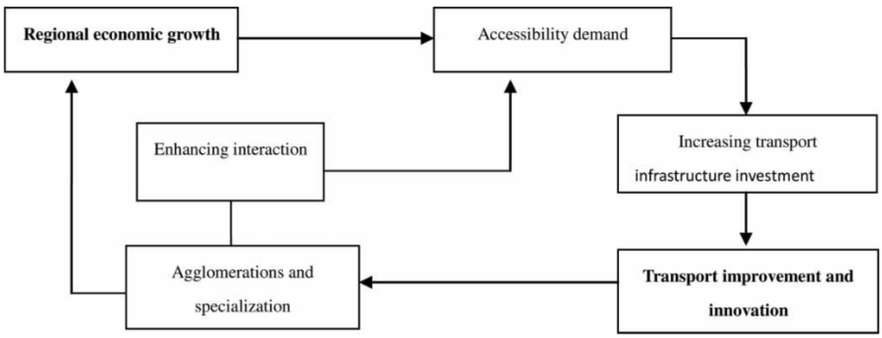

Figure 2-8. The feedback loop of economic growth to transport infrastructure

Note: This figure sourced from Zhang (2009).

Figure 2-8 shows the feedback loop of economic growth to transport infrastructure. With the economic growth and increasing job opportunities, many enterprises and families re-locate, which may lead to a change in site attractiveness and then a change of accessibility demand. The governments have to make corresponding transport infrastructure policies to achieve economic goals on the analysis of evaluating transport network and local accessibility in different regions. These policies will remodel the scale and direction of transport infrastructure investment

The regional economic growth will lead to a growing demand for transport services as well, which is an impetus to transport network development. Assume that there are two variables, T_D and T_S. The former represents the demand of transport service brought by economic growth and the latter shows the supply of accessibility in regional transport network. There are three different relationships between the two variables: $T_D > T_S$, $T_D = T_S$ and $T_D < T_S$. If $T_D > T_S$, local transport network would become the "bottle-neck" resource of regional economic growth, and the powerful force of demand may stimulate the development of transport network as an inevitable consequence; however, if $T_D = T_S$ or $T_D < T_S$, the demand for mobility should not exceed its supply, and in this case accessibility demand is not supposed to be an impulse to transport development (Krugman, 1991; Fujita et al., 1999). According China's large scale and huge population, with the rapid economic development and urbanization, transport service demand is much greater than current transport supply, and thus this demand ought to significantly induce the increasing of transport infrastructure investment. This is because Chinese authorities wield enormous decision-making power over public resources, and they will give priority to invest in transport infrastructure in order to achieve on-going economic development.

Based on the analysis above, we can draw the following conclusions: transport infrastructure can have a positive impact on regional economic growth in both the short-run and the long-run. However we are not sure whether transport investment is a productive stimulus contributing to economic growth, or merely a consequence of that growth? Or is it both? Vice versa, the economic growth can be either a cause or a result of transport improvement. The rapid developing economy leads to a growing demand for transport services and provides necessary financial and technical support to transport infrastructure investment in order to meet this demand. Consequently, it is very likely that the causality between these two variables really exists and we would expect this causality to be bidirectional.

2.4. Granger Causality Test: data, methodology[10] and empirical findings

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[10] More details for the econometric methods, including panel unit root test, panel integration test and Granger causality test, can be found in Appendix A.

The causal relationship between transport infrastructure and regional economic growth is examined within the framework of Granger causality. The definition of the causality between two series, given by Granger (1969), is based entirely on the predictability. Essentially, X_t is said to cause Y_t if X_t contains information in the past terms that helps in the prediction of Y_t. In the reverse direction, the feedback from Y_t to X_t can be said to exist if a prediction of X_t can be significantly improved by taking into account of past values of Y_t (Jiwattanakulpaisarn et al., 2010). Therefore, the causal relationship between X_t and Y_t can be bidirectional if the causation is found to run in both-sided directions simultaneously. The question of Granger causality between transport infrastructure and China's economic growth is addressed using a panel data of 31 provinces and municipalities, through the period from 1978 to 2008. In order to determine whether the causality between transport investment and the economy vary between regions, we also conduct this exercise for a smaller eastern panel (12 provinces), central panel (9 provinces) and western panel (10 provinces). All the Chinese provinces are divided into three groups according to the definition provided by State Statistical Bureau of China, as noted in the introduction.

In this study, we establish the empirical model as follows:

$$\ln GDP_{i,t} = \alpha_{0,i} + \alpha_{1,i} \ln TR_{i,t} + \varepsilon_{i,t}$$

$$\ln TR_{i,t} = \beta_{0,i} + \beta_{1,i} \ln GDP_{i,t} + \varepsilon_{i,t}$$

Here, $\ln GDP$ is the natural log of real GDP; $\ln TR$ is the natural log of transport investment; ε is the error term; the subscripts *i* and *t* denote the Chinese province and the year respectively. The data are collected from a number of different official Chinese sources, including China Statistical Yearbook, Statistical Yearbook of China's 31 provinces, municipalities and PRC's Statistical Series of 60 Years. The data of transport infrastructure investment during 1966-1974 are unavailable from the official materials due to the political issues and data during 1974 -1978 are not well preserved, and consequently we use data from a panel of 31 Chinese provinces for the period 1978 to 2008 for which data is available on real GDP and transport investment. The separate data of investment in transport infrastructure can't be found in various sources and we have to adopt the data of "investment in transport infrastructure and postal service" from the Statistical Yearbook of provinces and municipalities.

2.4.1 Panel unit root tests

The definitions of Granger Causality have assumed that only stationary series are involved (Granger, 1969). To check whether the variables used in this study are stationary, we run panel unit root test on the provincial data of economic growth and transport infrastructure investment on first step. In order to eliminate the effect of commodity price, all the data has been deflated using overall retail price index based on 1978 price structure. All the series are expressed in log-form in order to reduce heteroskedasticity, equally as GDP=log (GDP), TR=log (TR). Then we run Panel Unit Root Tests, including LLC Test, IPS Test, ADF-Fisher Test and PP-Fisher Test[11]. The results are reported in Table 2-1 to 2-4[12].

As the empirical findings above show, when we run the panel unit root test on the original value of GDP and transport investment, the results show that the null hypotheses of a unit root cannot be rejected at 10% level; however, when we conduct the joint unit root test for the

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[11] LLC and IPS represent the panel unit root tests of Levine et al.(2002) and Imet al. (2003)respectively. ADF-Fisher and PP-Fisher represent the Maddala and Wu (1999) ADF-Fisher and PP-Fisher panel unit root tests, respectively. The LLC, IPS, ADF-Fisher and PP-Fisher examine the null hypothesis of non-stationarity.

[12] More details of the results are available upon request from the authors.

first difference of each of the two variables we are able to reject the null hypotheses. Thus, we can conclude that the log of these time series are *I(1)*, which means the panel data of the log of GDP and transport investment is integrated of order one in these four panels.

Table 2-1. Panel unit root test results for full sample

	Full sample							
	GDP		TR		∆GDP		∆TR	
	No trend	Trend	No trend	Trend	No trend	Trend	No trend	Trend
LLC	6.080	1.288	10.790	1.180	-8.945	-8.139	-13.991	-13.802
	(1.000)	(0.901)	(1.000)	(0.881)	(0.000)	(0.000)	(0.000)	(0.000)
IPS	14.262	1.293	14.642	7.265	-10.35	-9.029	-12.473	-12.865
	(1.000)	(0.902)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)
ADF-Fisher	1.966	58.19	0.666	11.87	222.93	187.32	263.02	257.62
	(1.000)	(0.468)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)
PP-Fisher	1.343	31.61	0.344	12.82	285.81	257.86	520.53	1296.0
	(1.000)	(0.998)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Probability values are given in parenthesis.

Table 2-2. Panel unit root test results for eastern provinces

	Eastern panel							
	GDP		TR		∆GDP		∆TR	
	No trend	Trend	No trend	Trend	No trend	Trend	No trend	Trend
LLC	1.766	-1.698	5.498	-0.763	-6.950	-6.831	-8.976	-8.651
	(0.961)	(0.045)	(1.000)	(0.223)	(0.000)	(0.000)	(0.000)	(0.000)
IPS	6.657	-1.732	8.121	2.617	-6.519	-5.525	-7.781	-3.750
	(1.000)	(0.042)	(1.000)	(0.996)	(0.000)	(0.000)	(0.000)	(0.000)
ADF-Fisher	1.276	34.957	0.240	7.288	81.716	66.231	96.91	88.35
	(1.000)	(0.020)	(1.000)	(0.996)	(0.000)	(0.000)	(0.000)	(0.000)
PP-Fisher	0.576	14.980	0.108	7.209	77.543	70.047	177.98	474.17
	(1.000)	(0.777)	(1.000)	(0.996)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Probability values are given in parenthesis.

Table 2-3. Panel unit root test results for central provinces

	Central panel							
	GDP		TR		ΔGDP		ΔTR	
	No trend	Trend	No trend	Trend	No trend	Trend	No trend	Trend
LLC	5.061	2.615	4.458	0.731	-3.612	-4.000	-3.600	-2.762
	(1.000)	(0.996)	(1.000)	(0.768)	(0.000)	(0.000)	(0.000)	(0.003)
IPS	7.294	3.033	5.585	3.362	-3.343	-4.030	-4.466	-4.596
	(1.000)	(0.999)	(1.000)	(0.999)	(0.000)	(0.000)	(0.000)	(0.000)
ADF-Fisher	0.023	2.992	0.043	0.396	27.41	30.56	34.61	33.98
	(1.000)	(0.935)	(1.000)	(0.999)	(0.001)	(0.000)	(0.000)	(0.000)
PP-Fisher	0.001	0.837	0.013	2.500	29.15	36.95	90.38	127.28
	(1.000)	(0.999)	(1.000)	(0.962)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Probability values are given in parenthesis.

Table 2-4. Panel unit root test results for western provinces

	Western panel							
	GDP		TR		ΔGDP		ΔTR	
	No trend	Trend	No trend	Trend	No trend	Trend	No trend	Trend
LLC	3.966	0.453	5.881	-0.885	-3.771	-2.762	-7.288	-7.706
	(1.000)	(0.675)	(1.000)	(0.188)	(0.000)	(0.000)	(0.000)	(0.000)
IPS	7.095	0.146	7.058	3.577	-4.979	-3.918	-5.975	-6.682
	(1.000)	(0.558)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)
ADF-Fisher	0.110	9.150	0.048	1.159	47.42	36.14	57.38	61.26
	(1.000)	(0.690)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)
PP-Fisher	0.072	3.933	0.009	1.141	61.80	50.38	110.71	479.39
	(1.000)	(0.985)	(1.000)	(1.000)	(0.115)	(0.000)	(0.000)	(0.000)

Note: Probability values are given in parenthesis.

2.4.2 Panel cointegration tests

Once the existence of a panel unit root has been established, the issue arises whether there is a long-run equilibrium relationship between the two variables. Given that each variable is integrated of order 1, we test for panel cointegration using Engle and Granger's (1987) two-step test. A panel function regression is undertaken by estimating the long-run model specified in Equations (1) and (2) in order to obtain the estimated residuals. We use LLC, IPS, ADF-Fisher and PP-Fisher methods to identify whether these residual series are stationary. If 1 it are stationary, we can conclude that the two variables are cointegrated.

The results of the cointegration residual test are reported in Table 2-5.

Table 2-5. Results of cointegration residual test for the nation and its regions

Region	Cointegration residual	LLC	IPS	ADF-Fisher	PP-Fisher
Full samples	Eq.（2-1）	-12.831***	-13.008***	261.82***	2120.94***
		（0.000）	（0.000）	（0.000）	（0.000）
	Eq.（2-2）	-13.455***	-9.045***	265.09***	1873.89***
		（0.000）	（0.000）	（0.000）	（0.000）
Eastern panel	Eq.（2-1）	-9.175***	-8.142***	101.98***	185.73***
		（0.000）	（0.000）	（0.000）	（0.000）
	Eq.（2-2）	-9.102***	-8.036***	100.50***	188.66***
		（0.000）	（0.000）	（0.000）	（0.000）
Central panel	Eq.（2-1）	-6.730***	-6.426***	62.24**	119.04***
		（0.000）	（0.000）	（0.000）	（0.000）
	Eq.（2-2）	-7.552***	-6.313***	61.02***	116.87***
		（0.000）	（0.000）	（0.000）	（0.000）
Western panel	Eq.（2-1）	-6.326**	-7.089**	83.70***	164.41***
		（0.008）	（0.042）	（0.000）	（0.000）
	Eq.（2-2）	-4.064**	29.853**	30.397**	22.642***
		（0.028）	（0.010）	（0.026）	（0.000）

Note: Probability values are given in parenthesis. ***, ** Significance at the 1% and 5% level.

Table 2-5 shows that all the residuals from Equations (2-1) and (2-2) are significant at the 1% or 5% level, which indicates that all the statistics significantly reject the null hypothesis of no cointegration. We obtain strong evidence of integration among these series. Thus, it can be predicted that ln GDP and ln TR move together in the long run, which indicates that transport infrastructure improvement can facilitate China's economic growth and vice versa. That is, there is a long-run equilibrium relationship between transport investment and economic growth at both the national and regional levels. The next step is to estimate this relationship.

2.4.3 Granger causality tests

According to Granger (1969), the existing co-integration relationship implies that there will be the unidirectional Granger causality at least, which is also applicable to panel data. GDP and transport investment is co-integrated, which means the causality between GDP and transport investment exists in the long run, however we are not sure whether it is the bidirectional or unidirectional causality. Given that the variables are cointegrated, a panel vector error correction model is estimated to perform Granger causality tests (Narayan et al., 2008). The Engle and Granger's (1987) two-step procedure is undertaken by first estimating the long-run model specified in Eq. (1) in order to obtain the estimated residuals. Next, the Granger causality is tested by using the dynamic error correction model.

$$\Delta \ln GDP = \pi_{1,g} + \sum_{p} \pi_{11i,p} \Delta \ln GDP_{i,t-p} + \sum_{p} \pi_{12i,p} \Delta \ln TR_{i,t-p} + u_{1i,t}$$

$$\Delta \ln TR = \pi_{2,g} + \sum_{p} \pi_{21i,p} \Delta \ln GDP_{i,t-p} + \sum_{p} \pi_{22i,p} \Delta \ln TR_{i,t-p} + u_{2i,t}$$

Here, all variables are as defined previously. *m* is the lag length set at 3 based on likelihood ratio tests, Δ denotes the first difference of the variable and $ECM_{i,t-1}$ denotes the error correction term. The significance of the first differenced variables provides evidence on the direction of short-run Granger causality, while the null hypothesis of no long-run causality in Equations (2-3) and (2-4) is tested by examining the significance of the t-statistic for the coefficient on the respective error correction term represented by λ (Banerjee and Carrion-i-Silvestre, 2006). For all i, the error correction mechanism is validated if the null hypotheses $H_0 : \lambda_{1i} = 0$ and $H_0 : \lambda_{2i} = 0$ are rejected and both the coefficients are negative (Engle and Granger, 1987; Hamilton, 1994). Table 6 reports the results for the panel Granger causality tests based on the ECM between GDP and transport investment for the nation, the eastern, central and western regions in both the short run and the long run.

Table 2-6. Results of Granger causality test

Region		$\Delta lnGDP$	$\Delta lnTR$	ECM_{t-1}
Full samples	$\Delta lnGDP$	-	0.021	0.032
			(1.89)	(0.46)
	$\Delta lnTR$	0.020	-	0.212***
		(1.89)		(9.02)
Eastern panel	$\Delta lnGDP$	-	0.016	0.034***
			(0.75)	(7.96)
	$\Delta lnTR$	0.133	-	0.932***
		(0.75)		(8.03)
Central panel	$\Delta lnGDP$	-	0.021	0.320
			(1.04)	(0.091)
	$\Delta lnTR$	0.299	-	0.191***
		(1.04)		(7.00)
Western panel	$\Delta lnGDP$	-	0.017	0.433
			(0.88)	(1.08)
	$\Delta lnTR$	0.158	-	0.232*
		(0.88)		(2.40)

Note: Probability values are given in parenthesis while t-statistics are given in square brackets. ***, **,* Significance at the 1% , 5% and 10% level.

From Table 2-6, we find similar results of the Granger causal relationship from these four panels in the short run. The econometric findings show that there is no causality between GDP and transport investment at both the national and regional levels with statistical confidence: all the first differenced variables are not significant due to the p-values being much greater than 0.05.

In the long run, at the national level, a causal relationship from economic growth to transport investment exists at the 5% significance level, while the converse directional causality cannot be found. At the regional level, the causal relationships between transport investment and the economy vary across regions. In the eastern region, the coefficients on the error correction term are negative and significant from both directions, which means that bidirectional causality between the two variables exists (Engle and Granger, 1987). For the central and western regions, there is unidirectional Granger causality from economic growth to transport infrastructure at the 5% level (or 10%). The results imply that a change in the rate of economic growth does cause a significant change in transport infrastructure investment with a confidence level of 95% (or 90%). Conversely, increasing transport infrastructure investment does not lead to a significant rise in regional economic growth rates in the central and western provinces. It is worth noting that this result does not imply that transport infrastructure has no impact on regional economic growth. It just indicates that the amount of transport investment at any point is not a reliable predictor of the level of economic activity at a later point in time in the central and western regions.

2.4.4 Discussion on the econometric findings

In this section, we conducted the co-integration and causality tests on the causal relationship between GDP and regional transport investment in China. From the econometric findings, the following conclusions can be drawn.

(a) In the short run, there is no causality between GDP and transport investment at both the national and regional levels. According to Section 2.3.1, infrastructure investment doesn’t have the character of a public good when the investment still does not become capital stock. In such a case, infrastructure investment would affect economic growth through a multiplier effect as other investments do. Additionally, as a kind of typical physical infrastructure, transport infrastructures take time to build and operate. It is not illogical that we cannot establish the causality between these two variables in the short term.

(b) In the long run, at the national level, the analysis supports that there is the unidirectional causality from economic growth to transport investment. The economic growth (GDP) is the Granger cause of transport infrastructure's development, which means that economic growth is indeed a major (statistically significant) cause of rapid development of China's transport infrastructure.

In such a case, the following reasons can be given:

According to Section 2.3.2, economic growth provides necessary financial and technical support for transport infrastructure investment and improvement. Typically, most infrastructures have been financed, built, owned and operated by the governments at the various levels (Newell et al., 2009). To fulfill the growing demand for transport services induced by economic growth, the governments are supposed to make effort on transport infrastructure construction. Since the Chinese government has the decision-making power over public investment, it gives priority to develop transport infrastructure through public-financed projects as well as organize construction projects through PPP and FDI (Han, 2009; Mu et al., 2010). Economic growth has significantly increased China's transport infrastructure investment and thus promoted transport development.

On the other hand, a feedback loop from transport investment to economic growth does not exist. The transport investment is not the Granger cause of China's economic growth, even though the improvement of transport infrastructure can facilitate China's economic growth. Besides transport infrastructure, the causes of regional economic growth hinge on numerous other factors, such as geography, level of technological development, human capital, culture, and political institutions. This finding is in line with the view of Zhang and Sun (2008), who also find the one-sided causality between China's economy and transport investment at the national level.

(c) In the long run, at the regional level, the causalities between transport investment and the economy vary across sub-national areas. The results of Granger Causality Test for the eastern panel show that the bidirectional causality between the two variables exists. That means, in the rich coastal provinces, transport investment is a productive stimulus contributing to its economic growth, meanwhile the booming economy creates demand for more transport services and gives regional governments great financial power to invest in transport infrastructure construction. Thus, the causality in the Eastern Region is two-sided. However, the results for the central panel and western panel, only one-sided causality from economic growth to transport investment can be found. The transport infrastructure investment can't be regarded as economy's Granger cause, even though the development of transport infrastructure can facilitate regional economic growth in the Central and Western Region. An improvement in transport infrastructure alone is not sufficient for stimulating economic growth in the under-developed areas. The technological and educational levels in the central and western provinces are very backward comparing to the coastal provinces. Thus, these regions cannot fully realize the promotion of economic growth brought by transport infrastructure.

More than transport infrastructure is needed to achieve regional economic growth in the Central and Western Region. That is to say, transport infrastructure alone cannot fully explain the observed variation in the growth performances of Chinese provinces. This finding is consistent with the view of Demurger (2001), who used panel data for a sample of 24 Chinese provinces, this estimation of a growth equation implied that the differences in geographical location, educational level and telecommunication facilities do account for a significant part of the observed variation in the growth performances of provinces in China as well as transport infrastructure.

Take the “Western Development Strategy” as an example. In the last two decades, China made a great effort to develop poor western provinces in order to reduce regional disparity and make the society steady, since Tibet and Xinjiang have had political issues since foundation of the People's Republic of China. Chinese government has invested a lot in transport infrastructure construction of the western provinces, since “Western Development Strategy” in 1998, including the Ning-Xi railway, Yu-Huai railway, Qing-Zang railway, Chongqing subway and the western highways construction (Report of Western China Economic Development, 2009). However, the technological and educational aspects have been neglected. The data from National Development and Reform Commission of China illustrate that in the period 1998-2008, the total investment in fixed assets of western provinces rose to RMB 1.5866 trillion yuan and the average annual growth rate was 22%. Such growth rates are very uncommon around the world. Nevertheless, in the same period, the total investment in education there was only RMB 0.1821 trillion yuan (SSB, 2009). Due to the unsatisfactory levels of education and technology, the western provinces cannot achieve significant economic improvement, even though they have better transport infrastructure now.

2.5. Conclusions and policy implication for China

In this paper, we have examined the causal relationship between transport investment and real GDP in a panel cointegration and Granger causality framework. In addition to a full panel of provinces we also utilized smaller panels corresponding to China's eastern, central and western provinces to examine whether the causality between transport investment and the economy vary across sub-national areas.

Below we present main conclusions from this article and policy recommendations for Chinese governments:

(1) Both economic activities and transport infrastructure facilities are heavily concentrated in the eastern coastal provinces and spatial clusters. The clusters are like stair steps decreasing from the higher eastern China (rapid growth, high incomes per head and a big infrastructure capital stock) to the lower western China (slower growth, lower incomes per capita and smaller infrastructure capital stock). This indicates that the development of transport infrastructure and regional economic performance go hand in hand in China.

(2) A one-way Granger causal relationship between transport investment and economic growth can be found at the national level in China. For the whole nation, economic growth leads to a growing demand for transport services and fulfils this demand by increasing public investment directly or organizing the large transport projects indirectly (Mu et al., 2011). The results of our panel cointegration test show that there is a stable long-run equilibrium relationship between economic growth and transport infrastructure investment. The improvement of transport infrastructure can facilitate China's economic growth, which is in line with the expectations of decision-makers. However, transport infrastructure investment is not the Granger cause of economic growth, which implies (statistically speaking) that regional economic growth is based on other sources than infrastructure investment. Besides transport infrastructure, the causes of regional economic growth hinge on numerous other factors, including investments in other things than physical infrastructure, geographical position, the level of technological development and human capital, as Demurger (2001) suggests.

(3) At the regional level, the Granger causal relationships vary across sub-national areas. Transport infrastructure development is found not to be an important engine for economic growth in the

low-income central and western provinces. An underdevelopment of other complementary factors is a likely reason for a lack of causality running from transport investment to economic growth in these provinces. It means that an improvement in transport infrastructure alone is not sufficient for stimulating regional growth. China's case shows that ample investments in transport infrastructure do not bring the benefits people expect in the underdeveloped areas. From a policy perspective, our results imply that the current infrastructure investment policies in the central and western regions are not effective, and an integrated package of investment (in education, technology, etc.) is urgently needed. Thus, Chinese governments should consider investment in transport infrastructure in the future investment planning in conjunction with complementary efforts to overcome other barriers to regional economic growth. For the central and western regions, in order to better realize the promotion of economic growth brought by transport infra- structure, as Zhang and Sun (2008) note, local governments should also highlight the cultural and educational development, improve science and technology, change the role of government and thus enhance the soft side of the region's competitive edge in order to shorten the gaps with the coastal eastern provinces.

Chapter 3

Growth impact of transport infrastructure investment in China: A regional analysis[13]

3.1. Introduction

China has seen steep economic growth since the economic reforms started in 1978. Along with the increase in GDP, China has experienced a rapid expansion of the transport network. According to many authors (Lou, 2003; Fan *et al.*, 2004; Zhang, 2009), the transport network growth has been one of the major engines of China's economic growth. Transport infrastructures include roads, railways, ports, airports and waterways and typically, these infrastructures have been financed, built, owned and operated by the governments at the

[13] This chapter is a slight adaption of Yu, de Jong and Storm (2012), published with the following title: The growth impact of transport infrastructure investment: a regional analysis for China (1978-2008).

various levels (World bank, 1994; Newell *et al.*, 2009). The question how these investments can be managed effectively and equitably is a critical problem of the various (central and provincial) governments.

One of the main challenges China still faces is the unequal development among Chinese regions. According to the official regional classification (SSB, 2009), China can be divided into three parts, based upon standards of economic development and geographic position, as shown in Table 1-2 of Chapter 1.

China's economic activities have for a long time been mainly concentrated in its eastern areas, such as the Yangtze River Delta (e.g. in the provinces of Zhejiang, Jiangsu Province and Shanghai City), the Pearl River Delta (e.g. in Guangdong province) and the Bohai Baky Region (e.g. Beijing, Tianjin, Southern Liaoning province and Shandong province) (Zhang and Sun, 2008; Tan and Yang, 2009). The western provinces have been lagging behind in terms of economic development (and average living standards); it is for this reason that since the mid-1990s the Chinese central government has been paying much more attention to the development of the backward western provinces. In particular, both central and local government have poured large sums of money in transport infrastructure construction in the western provinces, but the economic benefits created by these investments have remained far more modest than expected (Zhou, 2009). Compared with the western region, the central region enjoys a better geographical position, but the share of the central region in total transport investment has gone down (SSB, 2009) – even though it is an important connecting region. Thus, it is an important issue to identify the productivity effects of transport infrastructure at the sub-national level in order to determine whether the current regional investment patterns make economic sense or not.

Since Aschauer's (1989) original paper, many empirical studies have established a statistical linkage between transport infrastructure stock and economic growth in various countries in the past few decades. The main policy results from these studies concern the output elasticity of transport capital. In the recent literature, output elasticity results vary widely ranging from a very low 0.028 (Canning and Bennathan, 2000) to a very high 0.39 - 0.56 (Aschauer, 1989) or 0.33 (Munnel, 1990). Kamps (2006) used panel data for 22 OECD counties over the 1960-2001 periods and found an average elasticity of 0.22 (for all countries in the panel), while the individual country estimate for the UK was 0.18. A cross-country study by Canning and Bennathan (2007) showed that for developed countries the output elasticity of road infrastructure was 0.13 in the Cobb-Douglas (C-D) production function and 0.09 in the translog specification, respectively.

Meanwhile, a host of studies have been conducted on this issue for the case of China. Ma and Li (2001) analyzed the effects of the transport infrastructure capital stock on the private sector with the aid of an econometric model, and the output elasticity from 1981 to 1998 was found to be 0.55. Lou (2003) made an empirical investigation of the link between China's transport infrastructure investments and its long-term economic growth. The output elasticity of transport infrastructure capital from 1949 to 1999 proved to be 0.23. Zhang (2007) found the elasticity was 0.1061 using the data over 1993-2004. This diversity in the output is probably the result of differences between studies relative to special geographic scales of analysis, definition of investigation time as well as the underlying models that were chosen. In light of the above, we expect that analyses based on different geographic scales will lead to different results.

However, these national-level estimates of the output elasticity of transport capital are only of limited value for policymaking. The reason is that in view of the considerable disparity among the three Chinese regions under study here, we can reasonably expect that output elasticities take very different values for each of these regions. In other words, an analysis based on regions is necessary. Thus, this paper aims to estimate the impact of transport stock on overall economic growth, and on growth at the regional level, in order to identify whether there is variation in the productivity effects of transport capital stock across sub-national areas. The rest of the paper is organized as follows. In section 2, the differential expansion of transport infrastructure construction and also their utilization in China's regions in the previous decades are introduced. Section 3 will give the empirical analysis, including the methodology and main findings from statistical sources. Section 4 provides a discussion of the interpretation of our empirical findings in light of New Economic Geography theory. The conclusions and implications of this article are given in the concluding section.

3.2. The development of transport infrastructure in China and its regions

3.2.1 The expansion of transport infrastructure construction

The development of China's transport infrastructure has been shaped by various policy and institutional reforms that took place in the country over the past 60 years (Fan and Chan-Kang, 2008). During the pre-reform period, the centralized decision-making structure applied to all kinds of investments, including those in infrastructure construction. In the 1960s, centralization implied that infrastructure investments were made to favor heavy industry, which had a particular influence on infrastructure equipment, especially transport facilities. The development of the transport network was emphasized in North-Eastern China, where most of the heavy industry was based. More specifically, railway development was favored over other types of transport, to carry huge quantities of raw material and resources at a lower cost from resource-rich provinces, such as Shanxi and Guizhou, to the industrializing northeastern provinces. As a consequence, the national government made substantial efforts to expand the railway network rather than to upgrade existing routes

(Demurger, 2001).

Since the economic reforms began in 1978, and especially since the fiscal decentralization in the 1990s, there has been a significant increase of the investment in various types of transport facilities. Both the central government and the local governments chose to construct better transport infrastructure in order to attract FDI (foreign direct investment) and investment from national state-owned enterprises. As Figure 3-1 shows, the total investment in fixed transport infrastructure assets was RMB 609.11 billion (in constant 1978 prices) in 2008, 76 times the size of the year 1978.

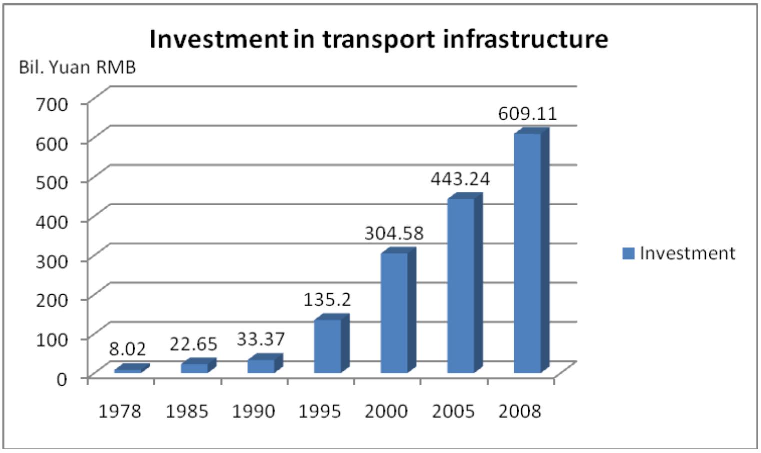

Figure 3-1. Investment trends for transport infrastructure in China

Note: Data were collected from China Statistical Yearbook (published by State Statistical Bureau) in various years. The investment figures were calculated in constant 1978 prices.

As a result of these high investment levels, the performance of China's transport infrastructure has improved markedly in the past decades. Apparently, all types of transport infrastructure have seen a significant increase in these years, as can also been seen in Table 3-1.

Table 3-1. Transport System Mileage in China

Year	Highways (x 1000 km)	Railways (x 1000 km)	Waterways (x 1000 km)	Civil aviation (x 1000 km)
1950	99.65	22.2	73.64	8.22
1970	636.74	43.79	148.42	42.50
1980	883.31	52.98	108.53	231.38
1990	1028.30	57.83	109.27	506.82
2000	1402.79	68.70	119.37	1529.14
2005	1960.71	77.54	127.41	2291.32
2008	3457.21	103.16	158.45	2714.09

Source: Data were obtained from the China Transportation Yearbook.

Despite great efforts to improve transport infrastructure, China's transport service is still insufficient to satisfy the huge demand induced by its booming economy (Zhang, 2009). The scale of the national transport network is relatively small, and traffic congestion is aggravating in Chinese metropolises (Wu, 2009). China is well known for its high traffic density. Compared with other countries, China's railway system has endured a high burden for a long time. As we can see from Figure 3-2, the figures for China are substantially higher than those for India, which has a huge population like China.

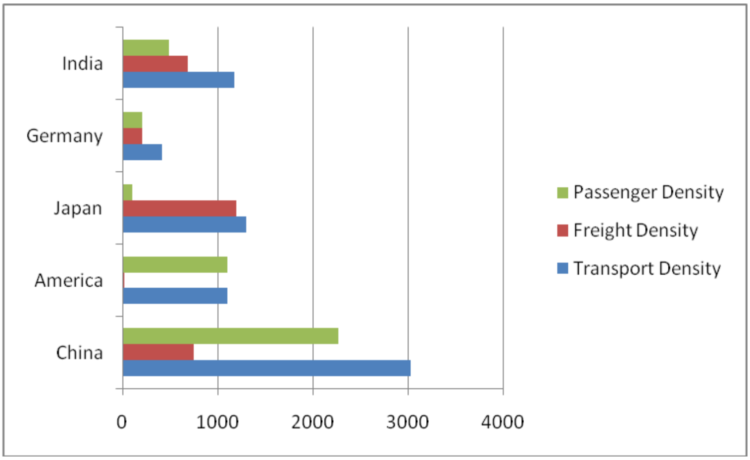

Figure 3-2. Cross-national comparison of railway transport densities

Note: Passenger density is expressed in person/km, freight density in ton*km/km and transport density in km/km^2. Data were collected from Wu (2009).

To conclude, China has witnessed a great improvement of its transport facilities. Nevertheless, its transport system is still incapable to completely fulfill the daily demand of passengers and enterprises. For China, a new round of "transport bottle-necks" is emerging due to the booming economy and its growing demand for mobility.

3.2.2 The regional disparity of transport infrastructure distribution

Given China's large scale, there are various geographic conditions in different parts of China for building infrastructures, as we described in Table 3-1. Apart from differential natural geographical conditions, China also has experienced growing interprovincial inequality during its transition process to a market-based economy. The region-biased policy has driven the largest portion of public investment to the coastal eastern regions (Yang, 1990; Tang, 1993; Wei, 1999). In the early stages of the economic reform, China carried out the "ladder-step development strategy": the government encouraged certain regions to "get rich quickly" (Wei 1999). This has led to higher economic growth and a more advanced infrastructure in the eastern region since 1978. With the fiscal decentralization which started in 1994, local governments have gradually taken over the discretion over infrastructure spending (Zhang *et al.*, 2007). As can be seen in Figure 3-3, the transport infrastructure investment in the eastern region has seen a tremendous increase in the mid-1990s and witnessed an especially sharp rise after 2002. Apparently, due to the favorable natural conditions and a biased investment policy, the local governments of the eastern region have had ample opportunity to implement large transport projects. Although the ratio invested in the Eastern region has declined in recent years, it still accounts for 50% of the country's total investment. In terms of the transport stock, the eastern region accounts for 31% of the country's total land area while it accounts for 57.74% of the country's transport infrastructure stock in 2009 (Ministry of Transportation, 2010).

As a result of fiscal decentralization, the ratio in the poor western region declined after 1985, but it rose again after 1998. The main reason for this reversal was the new strategy to develop the western regions, the implementation of which began in 1998. Following this new policy, the central government offered favorable financial terms for infrastructure investments and promoted direct investment in the western provinces. These policies brought the infrastructure standards of the western provinces to a higher level. However, in spite of these efforts, the economy in the western provinces did not grow as significantly as the government officials expected. As the 'Annual Report on Economic Development in the western Region of China' (Yao and Ren, 2009) indicated, since the western development strategy was enacted in 1998, annual GDP growth was at 11.42%. However, the annual growth ratio of the total fixed assets investment there reached 22%. Meanwhile, the gap between the eastern and western region is not narrowing, but slightly widening: GDP per capita of eastern region was 2.61 times higher than per capita GDP in the western region in 1998, and this ratio increased to 2.68 in 2008 (Yao and Ren, 2009). Table 3-2 shows the current situation of transport development across regions in 2008.

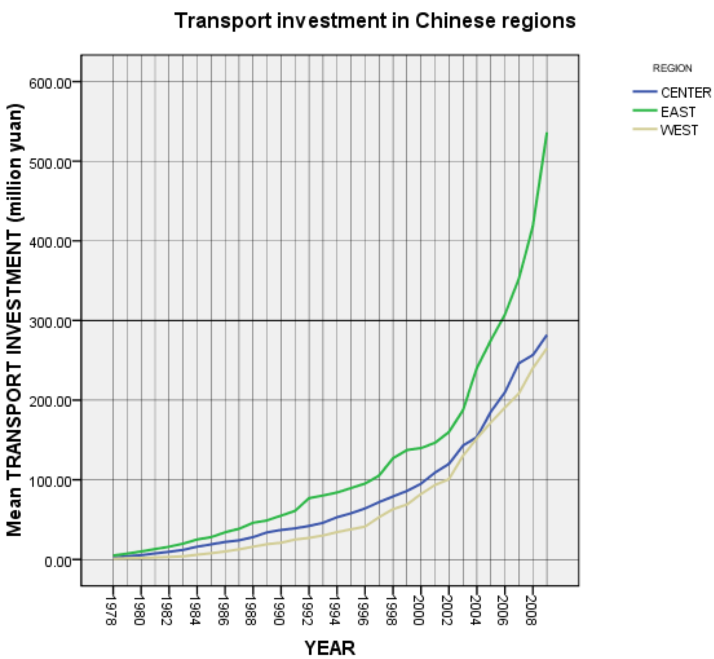

Figure 3-3. Regional variation of transport infrastructure investment in China

Note: Data were calculated by the authors based on the China Statistical Yearbook in various years (2005-2009) and Statistical Series of 55 Years of People's Republic of China (1949-2004).

Beside the regional disparity of transport infrastructure, the quality is also unequally distributed among different regions. According to their level and quality, roads are classified into six classes from high to low, as defined by 'Technical Standard of Highway Engineering in China'. Figure 3-4 shows the shares of different class roads[14] among the three regions. Apparently, the western and central regions are poorly served by roads of high class compared to the coastal region.

Table 3-2. Transport development and economic growth across regions in 2008

	East	Center	West
Highway mileage (10^4 km)	108.71	91.47	131.89
Population (10^4 person)	57618	45515	34495
GDP per capita(10^4 yuan)	3.41	1.78	1.25
Transport investment per capita (yuan)	903.80	611.14	793.97
Travel mileage per capita (km)	1958	1542	1152
Cargo turnover per million square kilometers (billion ton*km)	419.67	103.27	17.01

Note: Data were calculated by the authors based on the China Statistical Yearbook in 2009.

[14] Note: The definition of these class roads is given in the Chinese official file (No. JTJ001-1997) of 'Technical Standard of Highway Engineering in China': Highway: average daily volume is 25 000–100 000 cars. Class roads include four classes according to their average daily volume. Class 1: average daily volume is 15 000–55 000 cars; class 2: average daily volume is 3000–7500 medium-duty trucks; class 3: average daily volume is 1000–4000 medium-duty trucks; class 4: average daily volume is 200–1500 medium-duty trucks; substandard: average daily volume is less than 200 medium-duty trucks.

Finally, Figure 3-3 shows that the transport investment in the central region has increased at a much lower growth rate than in the eastern region, even lower than the western region. And the data from State Statistical Bureau show that the share of the central region in national transport investment has been steadily declining, from 41.20% in 1978 to 27.53% in 2008 (SSB, 2009). However from Table 3-2, we can see that the central region indeed has a relatively low transport network density (both for passengers and freight). It may very well be due to the abovementioned recent policies. For the eastern region, the region-biased policy released a lot of funding to help its transport construction in the early stages of its economic reform. For the western region, the central government also offered favorable financial terms for infrastructure investments and promoted direct investment in the western provinces in the last decade. For the central region, the Chinese government proposed some policies – such as 'rejuvenate the North-East' and 'develop the Centre' - but no supportive financial budget-plans were attached to these new policies. We therefore surmise that the central region may have been neglected by the national government.

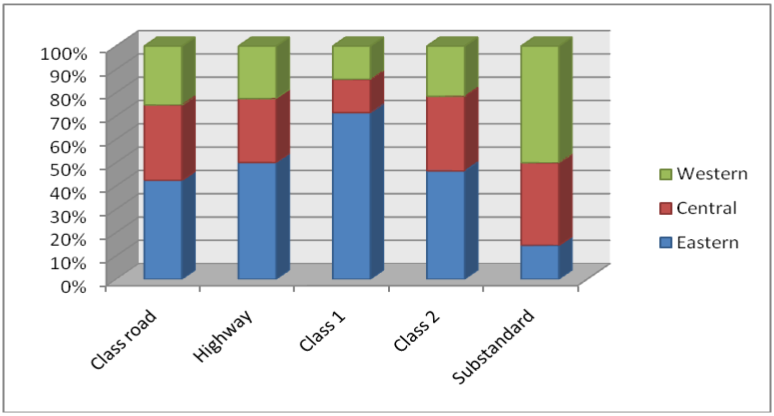

Figure 3-4. Quality disparity of road infrastructure between regions

Source: Yu et al. (2012)

3.2.3 Regional variation in the utilization of main transport services

Although the Chinese government has gone to great lengths to improve transport infrastructure construction, little attention was paid to the utilization of these new transport facilities at the sub-national level. According to the differential natural geographic conditions and economic performance, China's different regions performed differently on the utilization of their main transport facilities.

In recent years, traffic jams have aggravated in the eastern metropolises, where most enterprises are located. Especially during the Chinese Spring Festival season and the other important national holidays, passengers and freight transport on major facilities turn to be seriously congested (Ministry of Transportation, 2010). Most of the main railway links in the eastern region have been overloaded for a long time. Take the Jin-Hu (Beijing-Shanghai) Line as an example. Since the 1980s, the utilization ratio of the transportation capacity of Jing-Hu Line has been above 90%[15], which is far above the critical ratio[16] for railways. In that case, security and comfort levels cannot be guaranteed. Passenger transport for railways in the eastern provinces reached 304.82 billion passenger-km and freight transport, 911.07 billion ton-km in 2008[17]. Regarding highways, both the passenger and freight densities in the eastern provinces have increased in parallel with the booming economy and the multiplication of the number of

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[15] Data are collected from the Ministry of Transportation.

[16] The railway transportation capacity is not adjusted to drastic changes in weather conditions or technical breakdown when the efficiency of railway transportation capacity reaches 80%.

Available on line: http://wenku.baidu.com/view/8fd7d10b79563c1ec5da7168.html

[17] Data are collected from Transportation Statistical Yearbook in 2009.

enterprises there. In 1999, the freight transport for highways was 205.96 billion ton-km while it was at 1404.37 billion ton-km in 2008 (SSB, 2000, 2009). As the economic heart in China, the eastern region has been badly affected by transport congestion, and the Chinese government has made an enormous effort to reduce congestion, by constructing several high-speed railways connecting various metropolises. However, there is not enough space for development in the coastal area for such a booming economy due to its high intensity for land development[18] and scarce resources. It is imperative for the Chinese government to find a valid way to resolve this problem in order to develop a sustainable economy.

For the western part, all the official data clearly indicate that the Chinese government has begun to emphasize investment in western transport infrastructure construction (Wu, 2009). However, investments in highway construction, which accounted for a large part in the total, did not bring much improvement to the utilization rate (Liu *et al.*, 2009). The highway network density reached 20.7 km/hundred km^2, the 2.67 times more than that of 1999. Rather the opposite happened, highway freight density actually decreased to 4263 ton/km in 2008 from 5822 ton/ km in 1999[19]. The utilization efficiency of the main transport services declined with the expansion of transport infrastructure due to the larger scale and low population density in the western region. The main reason for this is that the western part can only be directly connected to the coastal region though waterways. However due to constraints in channel conditions, only the channel of Yangtze River between Yibin and the estuary near Shanghai can be used for large-scale transportation[20]. For railways, the

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[18] The development intensity in the eastern part reaches 30%, which is the highest intensity for land development, according to international standards.

[19] Data were collected from the People's Net. Available on line: http://news.sohu.com/20091209/n268815601.shtml

[20] Information was collected from news of Ministry of Transportation.

more efficient double-tracked lines are rare due to the complex geographic environment there, and the speed is also very low (Wu, 2009). The highways in the central region are still under construction, thus it is impossible to realize industrial transfer from the coastal region to the western provinces. Meanwhile, the highway projects inside the western region generate limited benefit due to the low transport-service demand there. Consequently, the poor connection reduces the utilization of transport infrastructures and thus the overall impact of transport investment on economic growth in the western region.

For the central region, we have seen that the investment in transport infrastructure did not increase as much as in the eastern and western regions. This is unfortunate because in recent years, the transportation network in this central connection area has become seriously burdened, both the railways and the highways. In 1999, railway freight density in the central region was 37453 ton/km, while it rose to 59001 ton/km in 2008. Rail passenger transport in the central region continued to grow, up to 334.88 billion passenger-km in 2008. Highway passenger transport in the central region reached 379.76 billion passenger-km and freight transport amounted to 1065.20 billion ton-km in 2008[21].

Six central region provinces, Henan, Hubei, Anhui, Jiangxi, Hunan and Shanxi, are called the "backland" of China because they link up the western with the eastern region, and also the south with the north. These connected provinces account for 10.7% of the country's total land area, but carry 28.1% of the total population (SSB, 2009). The traffic in the "backland of China" constitutes a very large proportion of that in the central region due to its important position, as Figure 3-5 displays. In 2008, freight density of the railways and

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Available on line: http://www.moc.gov.cn/zhuzhan/shuiluchuxing

[21] Data were collected from Transportation Statistical Yearbook in 2000 and 2009.

highways in the Backland was at 49043 ton/km and 10922 ton/km respectively. The transport burden in the connection areas constitutes a big problem for the further development of local cities and their neighboring areas.

Figure 3-5. Backland of China: six provinces in the central region

The above analysis reveals the existence of disparities in the distribution of transport infrastructures and their utilization in different regions in the last two decades. In spite of consistent efforts on the part of the Chinese government, the hiatus in economic development and welfare between the poor inland provinces and the "booming" coastal provinces has grown considerably wider. What is especially noteworthy is that disparities widened even though the government started to allocate a larger share of transport investment to the western region. This raises important questions. What is the real economic return of these investments in each region? Can current regional investment patterns be justified or are there reasons to argue for a different regional allocation of transport investments? To answer these questions, we will examine the output elasticity of transport investment at a regional level.

3.3. The output elasticity of transport infrastructure: methodology, data and findings

3.3.1 Methodology

Most scholars have studied the relationship between infrastructure investment and economic growth within the frame work of a C-D production function. A major problem in estimating a production function is the potential for reverse causation, as Romp and de Haan (2007) explain in detail. However, Canning and Bennathan (2000) in their paper "The social rate of return on infrastructure investments" argue that this causality problem can be resolved by a panel data approach, which is an argument generally accepted by most economists. We will follow earlier studies in using a C-D production function to estimate the output elasticity with respect to transport infrastructure capital stock, even though this approach is not without defects.

The general C-D production function can be written as:

$$Y = AK^{\alpha}L^{\beta}$$

Output Y (which is equal to real GDP at constant prices of 1978) is a function of the input of labor input (number of employed workers) L and the aggregate capital stock K. The scale factor A is generally interpreted as a measure of total factor productivity (TFP). To determine the separate impact on output of public infrastructure capital, the economy's aggregate capital stock K is split into three components (all expressed in 1978 constant prices): private capital stock K_C, public transport infrastructure capital stock K_T and other public infrastructure capital stock K_G. Following the literature we hypothesize that the impact on output of the different types of capital stock may vary. Therefore we define the following C-D production function:

$$Y = AK_C{}^{\alpha} L^{\beta} K_T{}^{\gamma} K_G{}^{\tau}$$

Taking the log of the both sides of the equation (2), we have the following (3):

$$\ln Y = \ln A + \alpha \ln K_C + \beta \ln L + \gamma \ln K_T + \tau \ln K_G$$

In equation (3), all variables are as defined previously, and α, β, γ, τ represent the output elasticity of private capital, labor, transport infrastructure capital and other infrastructure capital. We note that, according to the neoclassical theory of production, the estimated output elasticity corresponds to the share in GDP of the factors of production. For instance, coefficient β can be interpreted as reflecting the share of wages (the payment for labor) in total GDP.

The contribution of transport infrastructure to sub national regional growth in China will be estimated with data from the Chinese provincial governments except Tibet and Hainan, where the geographic situation is quite different from the other provinces. Furthermore, data on Chongqing were combined with those of Sichuan province in this paper, because Chongqing has been a part of Sichuan province until 1997. Thus, we use a data set of 28 provinces and municipalities from 1978 to 2008 for the examination. The details about the data selection can be found in Appendix A. Appendix B reports the calculation method for transport stock.

We adopted the panel data method to examine the output elasticity of each input. Moreover, a Hausman test was used in order to choose the most accurate estimation method from the possibilities offered in the theory on the application of the panel data method.

3.3.2 Findings

Table 3-3 presents the statistical results at the national level[22].

Table 3-3. Output at the national level

Variable	Coefficient
Constant	2.1342 (0.63)
Labor	0.4551*** (10.18)
Private capital	0.1072 *** (4.02)
transport capital	0.1282 *** (6.02)
Other infrastructure capital	0.2984 *** (9.03)
R^2	0.93

**** Significance at the 1% level.*

Note: t-statistics are in parentheses.

The results from the econometric analysis show that the output elasticity of labor is 0.45 in China, much higher than any capital stock elasticity. The high labor output elasticity is a reflection of the high share of wages in the GDP (the value of the wage share is 44.7% in 2008[23]), which is the result of the relatively labor-intensive nature of Chinese production.

Compared with the elasticity of public capital (0.13 for transport and 0.30 for other infrastructure), China has a low output elasticity of

[22] More details of the calculation process are available upon request from the authors.

[23] Data are collected from China Statistical Yearbook in 2009.

private sector capital, 0.11. One could argue that the influence of market factors for local economic development gets reflected in the contribution of the private sector to the economic growth (Zhang, 2007). So we can infer that market factors do not affect economic growth as much as governments do in China. The output elasticity of the transport capital is 0.13, which is numerically slightly higher than the output elasticity of the private sector capital, 0.11. To check if the numerical difference is statistically significantly different from zero, we conducted a t-test. $T = (\gamma_T - \gamma_C) - 0 / S = 3.281$, which was substantially above the critical value (1.674). Therefore, the difference between transport output elasticity and private sector output elasticity is statistically significant (at 10%).

It will be clear that our estimated output elasticity of transport infrastructure (0.13) is much lower than the results from other Chinese scholars (0.39 on average), which have been discussed in the literature review. This result may be caused by the following facts:

(1) Part of the difference is due to a difference in time-periods studied. We used recent data for the period 1978-2008. In recent years, the national government has spent a lot on the transport infrastructure construction and as more and more investments are being poured into transport projects, the marginal returns are beginning to decline, although they are still positive and economically viable. This effect is captured in our estimation.

(2) Another part of the difference is due to the fact that both the central government and local governments have reinforced the transport investments in the western region in the last few years, but large parts of the new western transport infrastructure are used less intensely. The utilization factor of the transport in the western provinces is relatively low because of the low density of the population and because of the limited connections with the eastern part of the country, as we discussed in Section 3.2.3. Therefore, transport infrastructure growth is bound to have a more limited

impact on the economic growth and the output elasticity will be accordingly smaller.

The output of transport stock at the regional level is reported in Table 3-4[24].

Table 3-4. Output at the regional level

Region	Variable	coefficient
EAST	Constant	2.0480 *** (7.50)
	Labor	0.5683 *** (15.07)
	private capital	0.1671 *** (10.06)
	transport capital	0.0909 ** (3.06)
	other infrastructure capital	0.2118 ** (11.05)
	R^2	0.96
CENTER	constant	2.6365 ** (2.70)
	labor	0.4070 *** (4.09)
	private capital	0.0738 *** (8.02)
	transport capital	0.2363 *** (12.03)
	other infrastructure capital	0.1515 *** (6.03)
	R^2	0.89
WEST	constant	1.2411 *** (1.24)
	labor	0.0893 *** (3.18)
	private capital	0.1464 *** (6.03)
	transport capital	0.0777 *** (11.02)
	other infrastructure capital	0.3370 *** (7.03)
	R^2	0.94

****, ** Significance at the 1% and 5% level.*

Note: t-statistics are in parentheses.

24 Since the large municipalities Beijing, Tianjin and Shanghai (which are directly under central government control) have much higher transport densities than the other eastern provinces, a robustness test was performed by estimating the output elasticity of the other eastern provinces separately. Only minor changes in the output elasticities appeared. More calculation details are available upon request from the authors.

As can be seen in Table 3-4, the output elasticity of private sector capital in the eastern region is the highest, 0.17. And the output elasticity in the central region and in the western region are 0.07 and 0.15, significantly lower than the elasticity in the Eeastern provinces. This situation may be caused by the fact that there are already a good economic environment and advanced infrastructure facilities in the coastal provinces after decades of construction, so that the private sector investment there can obtain maximum returns. The eastern region also has a relatively high labor-output elasticity, 0.57, about 1.4 times higher than the central region and even 7 times higher than the western region. Most people employed in the rich coastal provinces are highly qualified. Meanwhile, plenty of cheap labor power from the central provinces has transferred to the eastern region in recent years, which would be the real reason to explain why the eastern region has such a high labor-output elasticity.

Table 3-5. Output of backland region

Variable	Coefficient
Constant	2.8413 ** (2.33)
Labor	0.3944 *** (3.23)
Private capital	0.0807 *** (10.03)
transport capital	0.3101 *** (6.04)
Other infrastructure capital	0.1742 ** (3.03)
R^2	0.90

****, ** Significance at the 1% and 5% level.*

Note: t-statistics are in parentheses.

The elasticity of transport in the central region is 0.24, which indicates that transport investment generates RMB 0.24 of GDP for every RMB 1 invested, keeping all other factors constant. The transport elasticity in the eastern region is 0.09 and in the western region is 0.08, which is far lower. In order to determine how the transport infrastructure in the Backland of China performed, a separate model was run using the data from these six provinces. The regression result is reported by Table 3-5.

The output elasticity of transport infrastructure there is 0.31, much higher than the other two regions, even higher than the whole central region, which means the investment in the central provinces except Jilin, Heilongjiang and Inner Mongolia will yield the highest economic benefits.

3.4. Application New Economic Geography to China

3.4.1 Impact of transport investment on economic growth vary across regions

Three important findings emerge from our empirical study. First, the contribution of transport capital to output indeed varies across regions with different characteristics. Second, our results are in line with Hansen's theory (1965) that the contribution of transport (highway) capital to state's output in intermediate regions is more pronounced than in the congested regions. Third, transport investment in the lagging region of China is unlikely to lead to a higher economic return.

The output elasticity figures of transport infrastructure are 0.09, 0.24 and 0.08 in the eastern region, the central region and the western region, respectively, which means that transport infrastructure makes the largest contribution to economic growth in the central provinces, followed by the eastern provinces and the smallest contribution in the western provinces. According to the t-test, where $T = (\gamma_{central} - \gamma_{east}) - 0 / S = -4.3$ (the critical value being -1.75), we should reject the hypothesis that there is no difference in the output elasticity of the transport in the central region and the eastern region. The difference is significant at the 10%-level. The same test was run between the output elasticity of the central and western regions, where $T = (\gamma_{central} - \gamma_{west}) - 0 / S = 12.8$ (the critical value being 1.75). Here, we should also reject the original hypothesis. Thus, we can draw the conclusion that there is spatial variation in the productivity effects of transport infrastructure investments.

The transport output elasticity of the central region is about 2.6 times higher than the elasticity of the eastern region and 3.3 times higher than the elasticity of the western region, implying that the transport infrastructure construction in the central provinces is most beneficial for the whole economy. More specifically, the elasticity of the Backland region is higher than the one of the full samples from the central provinces, which means these six provinces of the Backland region represent the most crucial part of the development of the central region.

The above can be explained as follows:

For the eastern region, new investment in transport infrastructure cannot lead to large economic benefits even though these provinces are faced with serious congestion problems. This is so because a mass of investment has already been poured into transport projects in the coastal provinces, and the coastal provinces already enjoy better transport services. Thus, the marginal returns have started to decline in the last two decades. And for the coastal region, the high level transport infrastructure may be the right choice, such as the high-speed train construction in Beijing, Shanghai, Zhejiang, Shandong and Liaoning.

The investment in the central region, especially in the Backland, will yield the highest economic returns. On the one hand, the central part is the connecting bridge between the western and the eastern part. The improvement of transport services in the central provinces would reduce the cost of commodity trade and technological spillover between the eastern and western region, and thereby increase the accessibility of the less developed western markets. On the other hand, this may reflect "the emerging of the new economic center", a proposition advanced by Fujita *et al.* (1999), who argue that there is a strong possibility that regions between current economic centers and peripheral regions can become the new economic centers in the future. We can conjecture that the central region will probably play a dominant role in the operation of the whole system.

The elasticity of transport in the western region is the lowest among all regions. The Chinese government invests heavily in the poorer western provinces hoping this may spur the economic development there. However, low efficiency in the utilization of the new transport facilities limits the economic revenue brought by the transport investment. This result contradicts some studies on the economic returns of transport facilities (Demurger, 2001), which argue that transport investment in the underdevelopment areas will generate higher benefits than in the developed regions. We observe that China has poured a lot of money in western transport infrastructure construction, while the educational and technological levels there continue to lag far behind. In such an environment, it is hard to realize the full economic benefit brought by such transport investment. Thus, underdevelopment of other complementary factors may be another possible reason for the low economic returns (Zhang and Sun, 2008; Yu et al., 2012).

Based on the discussion above, we can see that, at the regional level, the impact of transport infrastructure investment on economic performance varies significantly across sub-national areas in China. The investment in the central region, especially in the backland region, would yield the largest economic returns.

3.4.2 The application of New Economic Geography: where is the new economic center of China?

Our empirical findings are in line with "the emergence of economic center" theory (Fujita et al., 1999). In the book of "The Spatial Economy", Fujita, Krugman and Venables (1999) indicate that when congestion becomes a serious problem in the original economic center, a new center will emerge near the former one due to the combined effects of both centripetal and centrifugal forces[25]. If the new center is near the old one, or we can say that the new center exists in the shadow of the old one, and the centrifugal forces will still be strong. If the new center is far from the former one, the centripetal force will be too weak and ineffective. With the development of the economy, the new center is necessary because of transportation costs. And the new center will be established in the place where distance from the original center is acceptable. So the emergence of new cities is determined by the relative strength of centripetal and centrifugal forces. According to the theory, a new frontier city is created periodically as a result of catastrophic bifurcation of the existing spatial system, and the new frontier city is always the largest and grows the fastest. Thus, there is a strong possibility that the region between the current economic center and the peripheral regions can become the new economic center in the future.

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[25] About the centripetal and centrifugal forces, the details can be found in Krugman (1991), introducing these concepts in his Core-Periphery model. He used the two forces to explain how the interactions among increasing returns at the level of the firm, transport costs and factor mobility can cause spatial economic structure to emerge and change. The decreasing transportation cost would reduce the centripetal force that tend to pull labor and production factors into agglomerations and also the centrifugal force break such agglomerations up. But the centrifugal force would change more than the centripetal force with the decreasing transportation cost, thus the centripetal force will play a key part in the industrial transfer and induce the industrial agglomeration to one region, forming a Core-Periphery structure. Here, the centripetal force can include both pure external economies and a variety of market scale effects, such as the forward and backward linkages, and spillovers (Fujita et al., 1999), while the centrifugal force includes pure external diseconomies such as congestion and pollution, urban land rents, transportation costs, and the interests of moving away from highly competitive urban locations to less competitive rural ones.

Observing the Chinese circumstances in this theoretical light, the new economic center of China will be the central region, rather than the western region, which is too far removed from and too underdeveloped when compared to the eastern region. The Chinese government has realized that regional disparity is growing in recent years and chosen to emphasize the development of poor western provinces in order to reduce regional disparity and make the society steady, since Tibet and Xinjiang have had political issues since foundation of the People's Republic of China. However, the output of these large transport projects was unsatisfactory. The new transport facilities in the western region were too far away to help reduce the congestion of eastern metropolises. On the contrary, the provinces of the central region are located closer to the western region than the eastern ones and will therefore decrease the disadvantages of their geographic position by making them more accessible.

The improvement of transport facilities in the central part would play a key part in the rise of new economic center[26]. The lower transportation cost will facilitate the transfer of economic activities from the eastern provinces, because in the last decade, the eastern region developed propitiously and underwent an industrial expansion. Meanwhile, the central region began to benefit from the spillovers of the eastern region. Expansion of the transport infrastructure is a precondition for the emergence of a new economic center in Central China. The improvement of the market accessibility will speed up economic development in the provinces of the central region and enhance the industrial shift (from east to center), and encourage the provinces there to become the new economic center. The emergence of a "future economic center" would likely require a

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[26] Even though some studies argue that only transport infrastructure is not sufficient to boost the regional economy, they verify that transport stock can greatly facilitate the economic activities although there exists no Granger causality from transport investment to economic growth (Yu et al., 2012; Zhang and Sun, 2008).

change in the distribution of current transport investment patterns.

3.5 Significance and Policy Implications

This paper set out to estimate the impact of the transport stock on overall economic growth and on growth at the regional level in China and verified whether there was variation in the productivity effects of transport capital stock across sub-national areas. This proved to be the case and we have argued that the primary task for the Chinese government is to strengthen transport construction in China's central provinces, especially in the areas of the Backland of China with important cities such as Wuhan and Zhengzhou because of the highest productivity elasticity there. This conclusion is partly in line with Zhang (2007), but our study differs from Zhang (2007) in three ways. First, the elasticity of the Backland's transport infrastructure is estimated separately. Second, we made an attempt to explain our empirical findings from a New Economic Geography viewpoint. Third, the observation period was expanded (from 1978), and updated to 2008.

Based on the empirical findings and New Economic Geography theory, we conclude that it might be commendable for China to give priority to the development of transport facilities in its central region, especially in the Backland where the transport junctions are located. Three reasons can be given why transport infrastructure development in the central region is particularly critical to China's economic growth and the coordinated development of its regional economies.

Firstly, due to its intermediate geographic position, it will promote the connection between the outlying areas. The improvement in the transport facilities will reduce the costs of exchange between the west and the coastal regions substantially and the western parts will be drawn closer to the strong eastern market.

Secondly, the development of the transport infrastructure in the central region will shorten the distance between western and eastern China, therefore boost the relocation of Chinese economic activities. Some industries may move to western provinces if appropriate conditions become available, and these industries can tap into the specific resources and potential of those provinces because of industrial agglomeration effects.

Thirdly, accelerating the construction of transport infrastructure in the central region will improve the accessibility of the central area, which would be a boost to the emergence of a new economic center there. The development of infrastructures and the growth of the accessibility to other markets and regions will undoubtedly stimulate the development of the provinces in the area and the emergence of a new economic center. Meanwhile, improved transport service in the central region can significantly relieve the congestion and traffic jams in the metropolis of the eastern Region. Moreover, the development of the central region will provide rising employment, which can attract the population from regions where development is more restrained, such as the west. This may hinder the growth in the west to some extent, but the positive effects on the center will be stronger.

Chapter 4

Growth Impacts of education investment and its distribution in China[27]

4.1. Introduction

China has experienced a remarkable economic growth during its economic reform since 1978, but also a dramatic rise in economic inequality. From the foundation of the PRC to the end of 1980s, inequality across major regions measured by the coefficient of variation of per capita real GDP showed a downward trend, but it went up sharply in the 1990s (Fleisher et al., 2010). China's policy-makers are serious about keeping a balance between economic growth and social equality; as a result relevant public policies aimed to reduce the gap between regions have been enacted for the sake of

[27] This chapter is a slight adaption of Yu, Yu and de Jong (2015), published with the following title: Does educational inequality matter for China's economic growth?.

social stability and sustainable development. One of the important policies is the increasing investment in education as well as notable infrastructure investment in the lagging regions. Proponents of the endogenous growth theory argue that the difference in the average education attainment could affect total factor productivity, which will raise economic growth in the long run through its strong externalities (Romer, 1990; Barro, 1991; Benhabib and Spiegel, 1994). In other words, nations (or regions) with a high level of education attainment may keep a high growth rate for a long period. Thus, education is always considered an essential factor to influence regional disparity. The Chinese government expected the increase in education investment to stimulate productivity growth in the lagging regions. During the period 1998-2010, the average growth rate in education investment was about 20.6% in the Western Region, but only 16.2 % and 17.1% in the Eastern and Central Regions (Li, 2013). Since 2008, the average investment in education per capita of the Western Region has exceeded that of the Eastern Region because of the high growth rate for the last decade in the Western Region (NBS, 2009-2012a). However, the fact remains that the gap in economic disparity among regions did not narrow in the last decade; it even widened (Fleisher et al., 2010).

It is widely hypothesized that education has a direct impact on the economy through the generation of worker skills and also indirect effects through the facilitation of technology diffusion (Benhabib and Spiegel, 1994; Bils and Klenow, 2000; Fleisher et al., 2010), but why was the massive education investment poured into the poor west provinces not helpful to catch up with the coastal areas in China? Indeed, despite significant investment in education in many developing countries, economic development in those countries has not met expectations (Lopez et al., 1999; Castello and Domenech, 2002; 2010a; Wail et al., 2012), even though theories suggested a strong causal link from education to growth (Romer, 1990; Barro, 1991). One common explanation for this puzzle is that the distribution of education is often neglected in education investment planning and public policies. However, given the amount of investment in education, who gets educated matters a great deal (Lopez et al., 1999). The distribution of educational resources may also explain the regional variance in growth as well as the level of education attainment itself. Education cannot be fully traded on the free market as physical capital, thus the market mechanism cannot guarantee that education investments for different people generate equal marginal returns (Park, 2006). In that case, the aggregate production function depends on the distribution of education (equality in educational attainment) as well as on average educational attainment itself. Here, the increased equality in educational attainment means more equal distribution of education resource-expanding primary, junior secondary, and senior secondary toward much closer to universal enrollment rates as a priority, and not expanding higher education enrollment rates at a rapid pace right at first-and vice versa.

Realizing this, some scholars have tried to explore the link between educational distribution and growth. In empirical studies the relationship between inequality in educational attainment and economic growth was analyzed using cross-country data (Castello and Domenech, 2002; Bowman, 2007; Kumar and Kober, 2012); intra-country data (Hassan and Mirza, 2007; Digdowiseiso, 2009; Rodriguez-Pose and Tselios 2010; Gungor 2010; Zhang and Kong, 2010) or panel data (Lopez et al., 1999; Park, 2006; Klasen and Lamanna, 2009; Baliamoune-Lutz and McGillivray, 2009; Castello, 2010b). A good empirical literature review on the effects of inequality (including inequality in educational attainment) on economic growth can be found in Neves and Silva (2014). The impression emerging from the initial empirical studies is that inequality is negatively associated with growth (Birdsall and Londono, 1997; Lopez et al., 1999; Thomas et al., 2001; Castello and Domenech, 2002), suggesting a decreasing inequality in educational attainment with a higher economic growth and vice versa. However, this negative inequality-growth nexus argument has been challenged in other studies, suggesting an uncertain relationship between inequality and growth, and even positive association in several developed countries (Rehme, 2007; Rodriguez-Pose and Tselios, 2010; Castello, 2010a). Recent literature also identifies a robust non-linear link between inequality in education and economic development (Gungor, 2010; Wai et al., 2012). To summarize, there is no consensus on the question of whether inequality in education affects growth positively, negatively or at all.

For the case of China, most previous papers have focused on the impact of education attainment level on China's total factor productivity (Fleisher and Chen, 1997; Demurger, 2001; Fleisher et al., 2010; Zhang and Kong, 2010; Zheng and Hao, 2011), but little attention has been devoted to the influence of education distribution on economic growth. Recent empirical studies tried to measure inequality in educational attainment in China using education inequality indicators, but shed no light on the inequality-growth relationship (Qian and Smyth, 2005; Yang and Li, 2007; Cheng, 2009; Yang et al., 2014). In this article, we will examine the long run effect of inequality in educational attainment on China's growth using advanced heterogeneous panel cointegration techniques. The purpose of this paper is to identify whether inequality in educational attainment matters for regional growth in China, and whether this inequality is more relevant for growth than educational endowments. The contribution of this paper resides in a new effort to address the relevance of inequality in education distribution for China's economic performance and regional disparity, which may have important implications for education investment policy. This study also contributes to the methodology by overcoming the endogeneity problem of explainable variables plaguing previous studies on the inequality-growth nexus, since the changes in inequality in educational attainment may be a consequence of economic growth. Our paper tries to deal with this problem by employing panel cointegration techniques, which is a valid methodological technique to estimate a long-run relationship without the requirements of instrumental variables (Stock and Watson, 1993; Pedroni, 2000).

The remainder of this paper proceeds as follows. Section 2 provides a brief review of education development in China and the variance across China's three macro-regions. Section 3 presents the extent of inequality in educational attainment for China's 31 provinces measured by Gini coefficients of education distribution. In Section 4, we explain our methodology, describe our data, and report our empirical results and detailed discussion on long-run relationship between China's inequality in educational attainment and growth. Section 5 concludes and provides policy recommendations.

4.2. Education development in China and its regions

The Chinese government started to invest heavily in education in the 1950's, providing a nine-year compulsory education. Its social indicators outperformed those of other low-income countries. Chinese people enjoyed better health and education status than their counterparts in low-income countries even before the policy reform (Lopez et al., 1999). Since the economic reform in 1978, especially accelerating after the fiscal reform in 1994, education in China has experienced remarkable changes both quantitatively and qualitatively.

There is evidence for China's fast education development. The illiteracy rate of the Chinese population has dwindled from 33.58 percent in 1964 to 4.08 percent in 2010, and the number of people receiving the secondary education per 10^5 persons rose to 38,788 in 2010 from 4,680 in 1964 (NBS, 2011c). Meanwhile, the number of students enrolled in tertiary school rose steadily since the economic reform and rises dramatically particularly after the 2000s. This is mainly because of an increase in the demand for higher education leading the government to implement an expansion policy for higher education in 1999. The total number of fresh college graduates increased more than six-fold from 960,000 in 2001 to 6.35 million in 2010, at an annual increment of 1 million per year (NBS, 2011a). Moreover, the increase in the number of domestic college graduates is only a part of the entire picture. Constant et al. (2011) demonstrate that the numbers of Chinese students studying abroad have also increased dramatically because of the booming economy and the support from the Chinese government. That is to say, China's impressive achievements in education have not been fully appreciated in the scholarly literature (Li and Xing, 2010; Fleisher et al., 2010; Heckman and Yi, 2012).

Along with the rapid economic growth and expansion in higher education, disparity in education among regions in China was also obvious during the last two decades. That is possible since public schools are funded mainly at the local level: rich provinces tend to produce more human capital per capita than poor provinces. Resource constraints differentially affect access to schools for individuals in different segments of Chinese society. Particularly hard hit are children in rural areas and those in the West. Figure 4-1 shows the numbers of students enrolled in tertiary school per 10,000 persons in China's three macro-regions. It is obvious that the gap in higher education students between regions has been there since 1990, kept increasing after 2000, but slightly decreased since 2008.

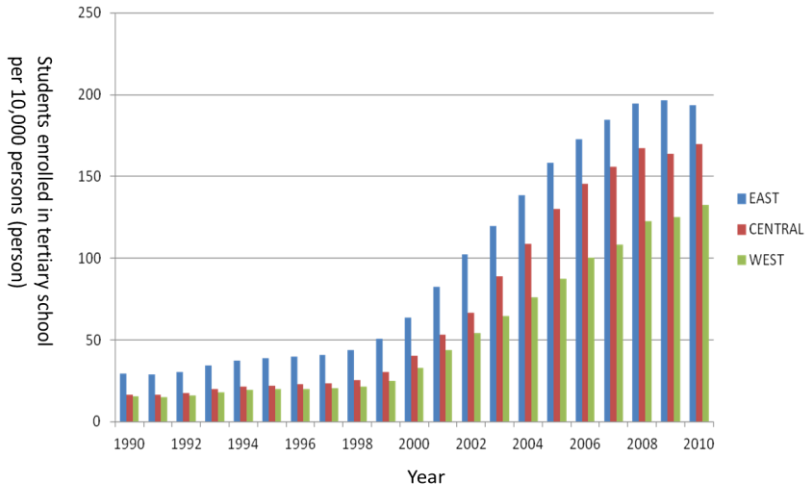

Figure 4-1. Numbers of students enrolled in tertiary school in Chinese regions

Note: This figure shows the change in numbers of students enrolled in tertiary school per 10,000 persons in the eastern, central and western region separately. The data are collect from China Statistical Compilation for Sixty Years (2009) and China Statistical Yearbook (2010 and 2011).

Moreover, the regional disparity in expenditure per pupil at the primary and secondary level (nine-year compulsory education) is also remarkable in China. At the primary level, public expenditure within the budget per pupil in the relatively well developed eastern region is much higher than the ones in the central and western regions, and this gap is gradually expanding since the 1980s. However, the central region had the lowest level of expenditure per pupil instead of the poorest western region during the period of 2000 to 2010. This is probably because of the priority policies the western region enjoyed in the last decade and also the low numbers of pupils. For instance, in 2010, the average expenditure per pupil within the budget in the eastern region is RMB 7562.02 *yuan*, but the numbers are 4563.28 and 5206.73 in the central and western regions, separately (The Financial Department of the Ministry of Education, 2011).

However, the investment data from the Chinese government show that in recent years, the interior provinces have a relatively higher investment in education per capita and also a higher growth rate than most coastal provinces, indicating that both the central and local governments in the lagging regions have noticed the disparity in education and tried to provide more financial support for educational development in inland areas, and hope rising education attainment levels can spur the local economy (Wang et al., 2007; Zheng and Hao, 2011; Li and Xing, 2010). Nevertheless, both the practice and statistical data also indicate that the economic gap between interior and coastal region did not narrow in the last decade. Meanwhile, the practice of many developing countries also tells us that education by itself does not guarantee successful development, because the levels of inequality in the distribution of education matter a great deal as well (Lopez et al., 1999; Thomas et al., 2001; Krueger and Lindahl, 2001; Castello and Domenech, 2002; Park, 2006). Thus, our paper will examine the distribution of educational resource for Chinese provinces measured by the inequality in educational attainment in next section, and then empirically investigate the long-term inequality-growth relationship in China in Section 4.4.

4.3. Measuring inequality in educational attainment in Chinese provinces

4.3.1 Method and data

In line with the previous literature, this paper adopts the education Gini index, a widely accepted measure of inequality in educational attainment, which measures the degree of inequality in the distribution of education by population quintiles (Barro, 2000; Castello and Domenech, 2002; Rehme, 2007; Rodriguez-Pose and Tselios, 2010; Zhang and Kong, 2010; Castello, 2010a,b).

The Gini index is generally calculated using information on attainment levels and the average schooling years of the total population aged 15 years and above. In detail, for each province we construed weighted distributions of years of education from which we computed the analogous education inequality measures to be used in the estimations. The following formula is used to accommodate the special features of the schooling distribution data. The education Gini coefficient can be calculated as follows.

$$Gini_{c,t} = \frac{\sum_{i=2}^{n}\sum_{j=1}^{i-1} p_{c,i,t}\left|y_{c,i,t} - y_{c,j,t}\right|p_{c,j,t}}{\sum_{j=1}^{n} p_{c,j,t}y_{c,j,t}}$$

(4-1)

Where, $Gini_{ct}$ is the Gini index of education of the province *c* at the time *t*; *p* denotes the cumulative population; *y* represents the average schooling years attained by each interval of the population; *n* corresponds with the level of education which is equal in our study to 5 levels：*i* and *j* are educational levels: $j=1$ for no formal education, $j=2$ for primary, $j=3$ for secondary, $j=4$ for higher secondary, $j=5$ for tertiary. The education Gini index measures the ratio to the mean (average years of schooling) of half of the average schooling deviations between all possible pairs of people (Thomas et al., 2001). The Gini coefficient takes values from 0 (0%) to 1 (100%): the higher the index the bigger the inequality in the distribution of education and vice versa.

The educational attainment level is proxied by the average schooling years per person in one province. Specifically, this indicator is measured as average years of schooling in the total population aged 6 and over, which can be calculated as follows: $AYS = \sum_{1}^{5} P_i NY_i$, where

p_i is the share of population with education level i; NY_i is the average years of schooling associated with the i'^{th} education category.

Considering the data limitations from various Chinese governmental statistical documents, this paper adopts the percentages for no schooling, primary, secondary, higher secondary, and tertiary and above attained by population of 6 years and over instead of 15 years and over. The total population number at different educational levels is computed based on the data of a 1‰ sample survey provided by China Statistical Yearbook (1997-2011). Data for the period of 1990 to 1995 is collected from China Population Statistical Yearbook (1991-1996). It is worth mentioning that the data for the years of 2000 and 2010 are different from those for other years, since China Statistical Yearbook did not give the population numbers at different educational levels, but China Population and Employment Statistics Yearbook (2001, 2011) provided the information we needed. Moreover, in China, the time for primary school is always 6 years; the time for secondary school is 3 years; the time for higher secondary school is 3 years; the time for the tertiary school is 4 years, but it is very difficult to quantify the population that received master and doctorate degrees. We therefore decided to consider all people who graduated and above as a group.

4.3.2 Education Gini index in China and its regions

Average schooling years and Education Gini coefficients for Chinese 31 provinces are calculated according to Eq. 1, some of which results in specific years are shown in Table 1. It can be seen that the education Gini coefficients declined in all the provinces with the increasing education attainment level during the period 1990–2010. For the nation, the average Gini coefficient declined from 0.32 in 1990 to 0.19 in 2010, suggesting an increasingly equal distribution of education over time. Furthermore, the education Lorenz curve for

China for the years 1990, 2000 and 2010, presented in Figure 4-2, also shows the narrowing tendency of inequality in educational attainment. The education Lorenz curve is constructed by putting the cumulative proportion of population on the horizontal axis, and by putting the cumulative proportion of schooling on vertical axis. Here, the *45-degree* line represents the situation where the distribution of education is perfectly equal. China's education Lorenz curve indicates that inequality in educational attainment has remarkably decreased over the two decades, especially during the period of 1990-2000, when Chinese government started its the education expansion strategy.

From a regional perspective, significant geographic variance in inequality in educational attainment can be observed as seen in Table 4-1. The Western Region has a relatively higher education Gini index, suggesting a larger inequality in the distribution of education attainment in those interior provinces. Indeed, the interstate disparity in the distribution of education attainment is still very obvious nowadays in China. For instance, in 2010, on the one side the Gini index in Beijing is less than 0.18, on the other, it is 0.46 in Tibet. Interestingly, regarding the difference in education achievement, the gap between regions appears to be not very significant in 2010 (the average schooling years are 7.85, 8.84, 9.22 in the western, central and eastern region, respectively).

It is worthwhile noting that the Gini index distribution pattern is inversely related to the spatial distribution pattern for China's economic growth: as our previous studies pointed out, in China, provinces with high levels of economic development are mainly located in the fertile coastal region; while most western provinces have very low levels of economic development (Yu et al., 2012). This fact suggests that inequality in educational attainment (measured by the education Gini coefficient) seems to be negatively associated with economic growth, but the exact effect of inequality in educational attainment on China's growth is still unclear. Thus we will empirically examine the long-run relationship between inequality in education and economic growth in China next.

Table 4-1. Average schooling years and education Gini index for Chinese provinces

Provinces	Average schooling years				Education Gini coefficient			
	1990	2000	2005	2010	1990	2000	2005	2010
Nation	6.59	7.71	7.93	8.69	0.32	0.24	0.22	0.19
East	6.96	8.02	8.42	9.22	0.27	0.23	0.23	0.20
Beijing	8.68	9.98	10.69	11.48	0.26	0.21	0.20	0.18
Tianjin	7.92	8.97	9.51	10.16	0.26	0.22	0.22	0.19
Hebei	6.37	7.68	8.17	8.87	0.30	0.22	0.21	0.18
Liaoning	7.46	8.41	8.75	9.46	0.24	0.21	0.20	0.18
Shanghai	8.26	9.30	10.03	10.54	0.27	0.22	0.21	0.20
Jiangsu	6.44	7.85	8.13	9.13	0.32	0.23	0.25	0.21
Zhejiang	6.16	7.45	7.61	8.63	0.32	0.25	0.26	0.23
Fujian	6.03	7.53	7.54	8.80	0.32	0.23	0.27	0.20
Shandong	6.25	7.58	7.72	8.76	0.32	0.24	0.25	0.22
Guangdong	6.76	8.07	8.36	9.23	0.27	0.21	0.21	0.18
Hainan	6.55	7.67	8.11	8.90	0.31	0.24	0.23	0.20
Centre	6.50	7.76	7.95	8.84	0.28	0.22	0.23	0.20
Shanxi	6.96	8.02	8.42	9.22	0.26	0.21	0.20	0.18
Inner Mongolia	6.58	7.75	8.22	8.99	0.32	0.25	0.26	0.21
Jilin	7.22	8.23	8.47	9.28	0.27	0.21	0.21	0.19
Heilongjiang	7.19	8.24	8.46	9.16	0.27	0.21	0.21	0.18
Anhui	5.35	6.97	7.04	8.12	0.40	0.26	0.29	0.24
Jiangxi	6.02	7.54	7.53	8.57	0.32	0.22	0.24	0.20
Henan	6.33	7.71	7.99	8.66	0.31	0.22	0.22	0.20
Hubei	6.45	7.76	7.82	9.01	0.32	0.24	0.25	0.21
Hunan	6.57	7.78	7.90	8.91	0.27	0.21	0.23	0.19
Guangxi	6.37	7.56	7.66	8.44	0.27	0.20	0.22	0.19
West	5.26	6.44	6.74	7.85	0.42	0.33	0.32	0.27
Chongqing	-	7.18	6.97	8.43	-	0.23	0.27	0.21
Sichuan	6.05	7.05	6.84	8.16	0.30	0.24	0.28	0.23
Guizhou	4.95	6.13	6.42	7.44	0.41	0.31	0.31	0.25
Yunnan	4.89	6.32	6.38	7.56	0.42	0.30	0.31	0.24
Tibet	2.36	3.36	3.74	5.28	0.72	0.60	0.51	0.46
Shaanxi	6.38	7.70	8.06	9.12	0.34	0.25	0.24	0.21
Gansu	5.16	6.52	6.86	8.01	0.45	0.33	0.32	0.26
Qinghai	5.21	6.16	6.76	7.63	0.46	0.39	0.37	0.30
Niangxia	5.73	7.01	7.37	8.50	0.40	0.31	0.31	0.24
Xinjiang	6.59	7.72	8.20	8.92	0.31	0.25	0.24	0.21

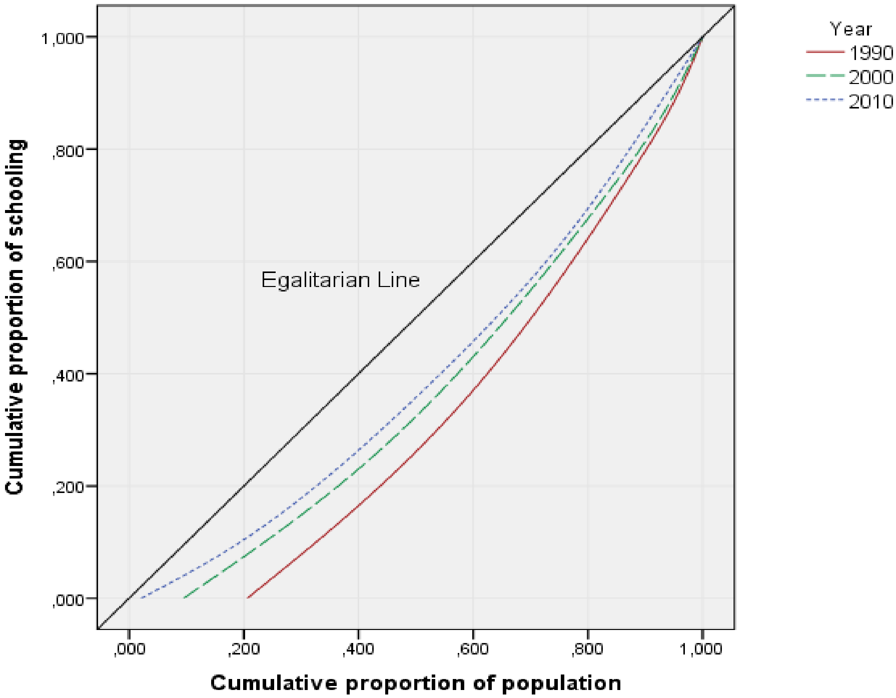

Figure 4-2. Education Lorenz Curve for China in 1990, 2000 and 2010

Source: Author's calculation based on the data from China Statistical Yearbook and China Population and Employment Statistics Yearbook.

4.4. Long-term relationship between inequality in educational attainment and economic growth in China

4.4.1 Methodology and data

In order to establish the long-run growth effect of inequality in educational attainment in China, we adopt panel cointegration, in which estimators are robust to a variety of estimation problems that often plague standard cross-country and panel regressions (Pedroni, 2007; Herzer and Vollmer, 2012). Given the focus of this study, our paper models the growth as a function of education variables (education attainment and inequality in educational attainment) and a series of other determinate factors, shown below.

$$\log(y_{it}) = \nu_i + \xi_t + \beta_{1i} EduAtt_{it} + \beta_{2i} EduGini_{it} + \gamma X_{it} + \varepsilon_{it}$$

(4-2)

Where y_{it} represents real GDP per capita; $EduAtt_{it}$ denotes the educational attainment level indexed by the average schooling years per person; $EduGini$ is the proxy for inequality in education; ν_i are province-specific fixed effects, ξ_t are time-specific parameters and ε_{it} is an error term; X contains a row vector of the factors determining GDP per capita, including investment (investment share of GDP), transport infrastructure development (transport density), population growth rate and unemployment rate.

First of all, in order to prevent estimating a spurious regression, the time series properties of the variables under study are determined before the estimation procedure is chosen. Testing for non-stationarity and co-integration benefits from adding the cross-section dimension to time series because the data base thus increases and the power of testing and estimation will be enhanced. Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Im, Pesaran and Shin unit root tests are performed on each series to determine their order of integration. The ADF unit root test involves estimating regression (3) for each series:

$$\Delta y_{it} = \alpha_{it} y_{it-1} + \delta_i + \theta_t + \eta_i t + \sum_{p=1}^{pi} r_{ij} \Delta y_{it-p} + \varepsilon_{it}$$

(4-3)

Here, i and t represent each province in the panel and time period separately; δ_i is the individual constant, θ_t is the common time effect and $\eta_i t$ is the individual time trend; p is the number of lags in the ADF process. The inclusion of the term $\sum_{p=1}^{pi} r_{ij} \Delta y_{it-p}$ accounts for serial correlation (possibly different across provinces) in the ADF regression errors. The null hypothesis of stationary is that α is identical across provinces and equals to zero, while the alternative hypothesis of unit root is that $\alpha < 0$ for at least one province. The PP unit root test involves estimating a non-augmented version of Eq. 3; i.e., without the lagging difference terms. PP unit root test uses a non-parametric method to control for serial correlation under the null hypothesis. H_0 and H_1 are the same as in the ADF test; however, PP unit root test is based on its own statistic and corresponding distribution (Phillips, 1987). Im, Pesaran and Shin (2003) use a test based on averaging individual unit root test statistics. They test the hypothesis that each series in the panel contains a unit root against the alternative that some (so not necessarily all) of the individual series have unit roots whereas others have not.

Results from these unit root tests would determine the procedure to be employed to estimate the long run effect among variables. For instance, if all series are integrated of order 0, then standard panel regression (ordinary least squares procedure, OLS) may be used; in contrast, if series are unit root non-stationary, then OLS would render a spurious regression. Once the series are found to be panel non-stationary and cointegrated of order one, we can claim that a long-run relationship exists between dependent and independent variables. Since fast growing provinces are likely to attract more highly educated individuals and also make great effort to reduce local inequality in educational attainment, there is the possibility of the existence of a two-way causal relationship between educational variables and economic growth. Thus, the regressors in Eq. 2 are likely to be endogenous, which leads to biased estimators if the OLS method is applied (Kao and Chiang, 2000). To deal with this problem, Eq. 4-2 can be estimated using the bias-correction method-the dynamic OLS (DOLS) approach developed by Stock and Watson (1993), which could eliminate the endogeneity of the independent variables by combining the lead and lag differences of explanatory variables to the cointegration equation (Pedroni, 2000). Thus, the cointegrating regression employing panel DOLS procedure to be estimated for our empirical study is the following:

$$\log(y_{it}) = \nu_i + \xi_t + \beta_{1i} EduAtt_{it} + \beta_{2i} Gini_{it} + \gamma X_{it} + \sum_{j=-q_i}^{p_i} \overline{\beta}_{1ij} \Delta EduAtt_{it-j} + \sum_{j=-q_i}^{p_i} \overline{\beta}_{2ij} \Delta Gini_{it-j} + \sum_{j=-q_i}^{p_i} \overline{r}_{ij} \Delta X_{it-j} + \varepsilon_{it}$$

(4-4)

Where the main variables are defined as in Eq. 4-2, and $\overline{\beta}_{1ij}$, $\overline{\beta}_{2ij}$ and $\overline{\gamma}_{ij}$ are coefficients of lead and lag differences of independent variables. Here, lead and lag terms included in panel dynamic least squares (DOLS) regression have the purpose of making its stochastic error term independent of all past innovations in stochastic regressors (Stock and Watson, 1993). Thus, DOLS regression could generate unbiased estimates for variables cointegrated without the requirement of exogeneity assumptions nor instruments, which is obviously better than ordinary least squares (OLS).

Table 4-2. Variable definition and statistical description

Variable	Definition	Max.	Min.	Mean	Std. dev
log(y)	The natural logarithm form of real GDP per capita	10.17	6.40	8.10	0.79
EduAtt	The average schooling years per person	11.48	2.25	7.35	1.40
EduGini	Educational Gini coefficient	0.73	0.18	0.28	0.08
TI	Transport density, measured by the sum of roads, railways and shipping line in one province divided by local land area.	2.88	0.02	0.45	0.39
Invest	Investment share of GDP	0.93	0.14	0.42	0.16
PGR	Population growth rate (%)	18.82	-2.30	7.70	4.35
Unemploy	Unemployment rate (%)	6.80	0.30	3.31	0.94

Data used in the empirical study are collected from various statistical documents, including China Statistical Yearbook (1998-2012), China Population Statistical Yearbook (1996-2005), China Population and Employment Statistics Yearbook (2006-2011), and Statistical compilations of the PRC for Sixty Years (1949-2009). The data on investment and GDP are converted to constant 1990 prices. The education Gini coefficient and average schooling years used here are from the calculation results of Section 3. Chongqing Municipality did not have separate data before 1997, thus we add Chongqing to

Sichuan province. Finally, the database used in the econometric analysis covers 30 Chinese provinces and autonomous regions over the period 1990 to 2010. Table 4-2 provides the variable definition and statistical description for our empirical estimations.

4.4.2 Empirical results

Table 4-3. Results of panel unit-root tests

		Variables						
		$\log(y_{it})$	$EduAtt_{it}$	$Gini_{it}$	TI_{it}	$Invest_{it}$	PGR_{it}	$Unemploy_{it}$
ADF-Fisher Chi-square	level	17.89	4.79	21.23	2.92	42.10	110.76***	18.83
	1st Diff.	111.71 ***	314.10 ***	271.16 ***	158.51 ***	127.66 ***	227.7***	186.54***
PP-Fisher Chi-square	level	19.77	2.79	19.77	2.20	15.49	312.50***	72.31
	1st Diff.	154.96 ***	602.91 ***	649.17 ***	301.99 ***	179.50 ***	425.27***	503.38***
Im, Pesaran and Shin W-stat	level	10.69	8.44	3.83	10.96	7.54	-2.78***	-2.28**
	1st Diff.	-3.92***	-14.86 ***	-12.86 ***	-7.36 ***	-4.92 ***	-10.41***	-8.57***

Note: **, *** indicates significance at the 5%, 1% level.

Panel unit-root tests

Table 4-3 reports the test results for the variables in level and in first differences. Results from unit root tests show that all the series except PGR under study are unit root non-stationary. In particular, all specifications of Levin et al., Pesaran, ADF and PP tests cannot reject the null hypothesis of a unit root process–at a 10% significance level–for all variables in level except *PRG*. Since the unit root hypothesis can be rejected for the first differences, it can be concluded that all the variables except *PRG* are integrated of order 1, *I (1)*.Given that all the series in the inequality-growth function are unit root non-stationary, the cointegrating regression by panel DOLS would be adopted in this study next.[28]

Long-term relationship

The DOLS estimates for the coefficients on inequality in educational attainment and other independent variables for explaining China's economic growth (based on equation 4-4) are reported in Table 4-4. In these estimations, there exists multi-collinearity between explainable variables, since the education Gini index is negatively associated with educational attainment level, with an ordinary correlation coefficient of -0.85. Econometric theory argues that differencing variable could reduce the multi-collinearity in a model (Pedroni, 2007). Thus, we choose differenced $EduAtt_{it}$ instead of the original series. The ordinary correlation coefficient between *EduGini* and differenced *EduAtt* is -0.05. Thus, *EduGini* and Diff.(*EduAtt*) could be estimated in the same model.

We start the analysis of the growth effect of educational variables, which we are mostly interested in. The results from both linear and non-linear models highlight the existence of a positive coefficient for educational attainment (column 1 and 2 of Table 4-4). This finding indicates, as expected, the importance of the overall education of the population as a factor for sustained regional growth (Rodríguez-Pose and Tselios, 2010). The positive coefficient also confirms the appropriateness of great effort put into education development made by the Chinese government in recent decades. For an emerging country like China, the average educational attainment level matters to the nation's economic performance a great deal.

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[28] Both the Johansen Fisher Panel Cointegration Test and Kao Residual Cointegration Test reject the null hypothesis of no cointegration at least at the 1% level, implying that there exists a long-run relationship between variables. More detailed information for the cointegration test is available from the authors upon request.

Regarding the inequality in educational attainment, a clear negative and statistically significant effect of the educational Gini coefficient on the per capita GDP can be observed from the linear model (column 1 of Table 4-4). This suggests that for Chinese provinces, a more even distribution of education (a fall in education inequality) is associated with an increase in output growth, and vice versa. Our finding is consistent with the empirical intra-country studies from the developing countries, such as Malaysia, Indonesia and sub-Saharan African and Arab countries (Baliamoune-Lutz and McGillivray, 2009; Hassan and Shahzad, 2007; Rao and Jani, 2008) and also worldwide cross-country data (Castello, 2002, 2010a). This result implies that in China, the educational attainment levels in the population also matters to growth as well as to education itself. The high level of inequality in education would hinder China's economic growth, a fact to which the Chinese government should pay special attention.

Furthermore, several recent studies have pointed out that there seems to be a non-linearity between inequality in educational attainment and growth (Gungor, 2010; Wai et al., 2012). Thus, our paper examines the possibility of a nonlinear relationship between economic development and inequality in educational attainment in China by including quadratic, cubic inequality in educational attainment terms in Eq.4-4. Our results show that a cubic polynomial function is still significant although the coefficient estimates in quadratic form are also significant, as shown in columns (2) and (3) of Table 4-4. Hence, we can identify a robust non-linear link between inequality in educational attainment and economic performance in China.

Specifically, Figure 4-3 plots the evolution of the Gini-growth nexus[29] in China over the period of 1990-2010. We observe a different

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[29] It is worth noting that in Figure 4-3 we change economic growth in the Axis Y and

effect of inequality in educational attainment on growth depending on the level of development of the region. This tendency is particularly clear from the smooth plots in this figure. When the level of economic development is extremely low, there seems to be a positive relationship between inequality in educational attainment and growth, while the effect of inequality in educational attainment becomes significantly negative after economic development reaches some critical level. The reasons behind this change appear to be complex.

In the earliest stages of economic development, an uneven distribution of education may play an essential role in a nation's take-off process. On the one hand, inequality may encourage members of the highly educated segments of society to increase their investment in education, while equality may trap the whole society into low levels of investment in education (Galor and Tsiddon 1997; Rodríguez-Pose and Tselios, 2010). On the other hand, it is also possible that at a very early take-off stage, the initial growth may generate some additional inequality both in the distribution of income and in educational attainment. For instance, at the early stage of PRC (the People's Republic of China)'s economic growth, Mr. Deng Xiaoping (the former chairman of China's Central Military Commission) proposed to 'let some people get rich first', which obviously encouraged the inequality in income and possibly also in educational attainment. That is why a positive inequality in educational attainment-growth nexus exists at the very early stage of China's development.

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education Gini index in the Axis X in order to see clearly how the Gini-growth nexus changes according to different economic developmental stages. The linear relationship between two variables will not change because of this switch. For instance, if X significantly positively associates with Y, Y definitely is positively associated with X.

Table 4-4. Estimation Results of the cointegrating regression model (DOLS and OLS estimations): the nation

	DOLS estimation			OLS estimation		
	Linear (1)	Quadratic (2)	Cubic (3)	Linear (4)	Quadratic (5)	Cubic (6)
Constant	-	-	-	8.68(101.15)***	9.43(63.24)***	12.44(37.41)***
EduGini	-4.75(-12.28)***	-12.92(-9.19)***	-32.98(-13.50)***	-2.80(-9.89)***	-7.23(-9.22)***	-33.03(-12.75)***
$EduGini^2$	-	9.81(4.80)***	57.23(8.93)***	-	5.26(6.03)***	62.18(9.42)***
$EduGini^3$	-	-	-30.22(-5.51)***	-	-	-41.61(-8.02)***
Diff.(EduAtt)	0.21(1.80)*	0.44(5.90)***	-	0.02(0.59)	0.02(0.72)	0.02(0.47)
Invest	1.74(13.46)***	1.44(14.02)***	1.85(20.00)***	1.08(14.53)***	1.09(15.00)***	1.08(15.93)***
TI	0.67(15.42)***	0.69(11.99)***	0.67(17.21)***	0.80(24.08)***	0.71(19.92)***	0.63(18.03)***
Unemploy	0.04(0.28)	0.12(1.31)	0.03(1.51)	0.03(2.68)**	0.02(2.03)*	0.01(0.78)
PGR	-	-	-	-0.08(-17.36)	-0.07(-14.64)***	-0.07(-15.17)
No. of Provinces	30	30	30	30	30	30
Observations	510	510	510	600	600	600
R-squared	0.99	0.99	0.99	0.94	0.95	0.95
Adj. R-squared	0.98	0.99	0.99	0.94	0.95	0.95
S.E.	0.10	0.04	0.05	0.19	0.18	0.17
Model Selection	Fixed effect	Fixed effect	Fixed effect	Fixed effect	Fixed effect	Random effect
Fisher test	-	-	-	F(29,565), 50.18	F(29,564),50.54	F(29,563),56.97
Hausman test	-	-	-	15.04	16.42	13.41
Leads	1	1	1	-	-	-
Lags	1	1	1	-	-	-

Notes: *, **, *** denotes statistical significance at 10%, 5% and 1% separately; t-statistics appears in parenthesis.

However, as development proceeds, the inappropriate human capital structure induced by high inequity in education, creates a situation where skilled workers cannot meet the requirements for modern technology diffusion and applications. Technology diffusion and technology application are critical factors to increase total factor productivity in a society (Zhang and Kong, 2010). During this period, rising equity in education is essential for economic growth and development. Moreover, at lower stages of development, the social rates of return relevant to basic education are higher than for higher education when it is expanded too early. This would certainly imply that greater equality of educational attainment is conducive to faster growth (Psacharopoulos and Patrinos, 2004). Hence, for the regions at this developmental stage, reducing inequality is a key contributor for generating local growth.

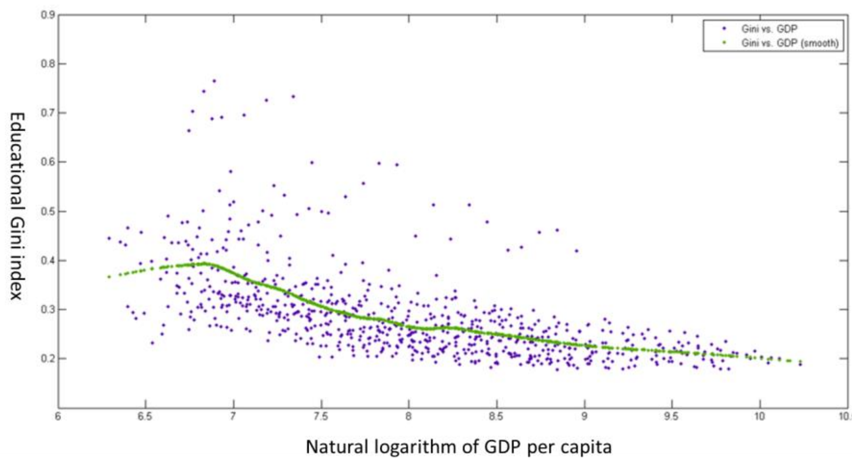

Figure 4-3. The relationship between educational inequality and economic growth in China (pooled data)

Note: In Figure 4-3, Axis X denotes economic performance (the natural logarithm of GDP per capita) and Axis Y represents the level of educational inequality (measured by education Gini index. We clarify the tendency of correlation by ‘smooth’ tool provided by MATLAB.

As to China these days, all provinces have passed the threshold value of development level (Guizhou has the lowest level of GDP per capita in 2010, 8.21 in the logarithmic form), thus a strong negative long-run growth effect of inequality in educational attainment can be confirmed, implying the importance of inequality reduction in Chinese provinces at this moment and also in the near future.

We have to point out that the correlation between inequality in human capital and economic growth is very complex, which cannot be explored by our data because of the limited observation period. For example, the negative relationship may be not sustained, even vanish or turn positive in higher-income countries where inequality appears to be very small, such as some west European countries (Rodriguez-Pose and Tselios, 2010; Digdowiseiso, 2009; Castello-Climent, 2010). It can be partly explained by the rate of return-at later stages of development, and to some extent in the more recent years, the social rates of return relevant to tertiary education are higher than the basic education, suggesting that an uneven distribution of education may be conducive to growth. The experience from developed countries also indicated that relative contribution of investment in tertiary education to growth would be very impressive only at the later stages of development (Cui, 2000). Thus, we speculate that the growth effect of inequality in educational attainment in China would further change according to the shift in developmental stage.

For the remaining results, the determinants have already been documented (Liu et al. 2010; Zhang, 2009; Yu et al., 2013), at least partially, in the existing literature on China's economic growth, and most of the coefficients are as expected. First, as expected, a positive effect of the investment variable can be confirmed from our empirical results. As physical capital is the major production factor input, different levels of capital stock (induced by investment) should contribute to growth differences. Second, estimations also indicate that the development of transport facilities has a positive impact on economic growth, which has been confirmed in many existing studies on China's economic growth (Liu et al., 2010; Yu et al., 2013). Thirdly, the effect on the unemployment rate is unstable, since the regression coefficient is sensitive to the inclusion of other explanatory variables.

Moreover, optional econometric estimations of Eq. (4-2) (OLS) reported in the left panel of Table 4-4 provide some additional evidence on the impact of population growth on economic growth. This variable cannot be added to the panel cointegration model since "PGR" is not integrated of order 1 with other variables. The results show that the association between population growth rate and per capita GDP is significantly negative (column 4-6 of Table 4-4), which has also been reported in previous studies (Castello-Climent, 2002; Gungor, 2010; Wai et al., 2012).

Inequality in educational attainment-growth nexus in the lagging areas

In order to highlight the role of education distribution in economic growth in the lagging western areas, we estimate Eq. (4-4) for the western provinces separately. Here, the lagging area under observation gathers a group of western provinces, including Sichuan, Guizhou, Yunnan, Shaanxi, Tibet, Gansu, Qinghai, Ningxia and Xinjiang.

Table 4-5 displays the estimation results for the lagging areas. The inequality-growth nexus continues to be significantly negative in these poor regions. However, it is worth noting that the inequality in educational attainment seems to be more important to local economy than average education attainment level in these poor regions. For the lagging areas, the coefficient on educational attainment is positive, but not significant. Meanwhile, the coefficient on inequality in educational attainment (-3.70) is significant and much higher than the estimated coefficient of education attainment (0.07), as displayed in column (3) of Table 4-5. Hence, these findings suggest that inequalities in educational attainment levels matter more for local growth than average educational attainment in the lagging western regions.

Table 4-5. Estimation Results of the cointegrating regression model (DOLS estimation): the lagging areas

	(1)	(2)	(3)
EduGini	-2.78(-5.21)***	-	-3.70(-7.83)***
Diff.(EduAtt)	-	0.05(0.14)	0.07(0.83)
Invest	1.90(6.03)***	3.23(13.93)***	1.12(4.97)***
TI	0.78(3.46)***	0.52(1.75)	0.20(1.44)
Unemploy	0.31(1.25)	0.27(1.02)	0.25(0.12)
No. of provinces	9	9	9
Observations	162	153	153
R-squared	0.97	0.97	0.99
Adj. R-squared	0.97	0.96	0.98
S.E.	0.11	0.12	0.08
Lead	1	1	1
Lag	1	1	1

Note: *** denotes statistical significance at 1%; t-statistics appears in parenthesis.

Chinese government has invested more in education in the lagging western region since the early 2000s. Education improvement is an important part of the Western Development Strategy. However, no positive effect of these education investments became apparent. This is probably because of the uneven distribution of these education investments among the population in the western provinces. Hence, this finding could partly explain why rising investment in education in the western region and widening regional inequality exist simultaneously in China.

Interestingly, the coefficients of transport infrastructure are not significant in regressions (2) and (3) of Table 4-5, which may lead us to question the appropriateness of transport-stressed investment policies in the lagging western areas (Yu et al., 2013). In contrast, the importance of education both for education attainment and its distribution seems to be unmistakable.

4.5. Concluding remarks

This paper analyzed the distribution of education in China measured by the educational Gini index, and empirically explored the correlation between inequality in educational attainment and economic growth using heterogeneous panel cointegration techniques. First of all, we provide inequality in educational attainment measured by education Gini index for 31 Chinese provinces over a relatively long period of 1990-2010 with annual observations. Secondly, an important finding that complements the findings of previous research is the non-linear relationship between inequality in educational attainment and economic growth in China. There appears to be a different inequality in educational attainment-growth nexus according to the level of a region's economic development in Chinese provinces. Thirdly, we evaluate the impact of inequality in educational attainment in the lagging western region separately and find that the distribution of education resource in West China matters more for economic performance than education attainment itself.

The policy implications of the above results are obvious. Our results suggest that the distribution of education is critical to China's growth, however the growth effect of inequality is complex and changeable with the shift in developmental stage. The Chinese government should consider the stage of development of a region when relevant policies to foster economic growth through education are made. For China at this moment, the negative effect of inequality in educational attainment is very strong. More equal distribution of education is desirable of itself for educational development and also consistent with the target of economic growth. That is because a developing country like China would perform better if it allocated its educational resources more evenly (the universal primary and near-universal secondary education is preferable), given the limited resources devoted to education. This argument is also partly confirmed by the studies on the contribution of investment in tertiary education to growth. The contribution rate of tertiary education in China appeared to be very limited, 2.04%, but the contrition rate of education on average (including primary, secondary and tertiary education) reached 5.69% (Li and Cha, 2006), suggesting the importance of basic education at current stage of China's development. Thus, for the purpose of growth, the Chinese government would better emphasize the equal distribution of education attainment. Moreover, our findings emphasize the key role of education distribution in West China's growth and development. For these areas that lag behind, equity of education is more important than average education level.

These insights on the importance of equity provide a basis for China's education policy. Thus, the Chinese government should heed the question how it spreads its investment resources in education over its population, especially in the lagging regions, if it wishes to optimize its education policy.

Chapter 5

Public infrastructure, economic activities agglomeration and spatial disparity in China[30]

5.1. Introduction

China has witnessed growing coastal-interior and urban-rural inequity in terms of average income and other economic or social welfare indicators during its recent decades of rapid economic growth. The manufacturing sector is also highly concentrated in East China, where nine coastal provinces accounted for 69 percent of the manufacturing output value in 2012 (China City Statistical Yearbook, 2013). The spatial development pattern of core-periphery (coast-interior) has already firmly taken shape in China, and how to

[30] This chapter is a slight adaption of Yu, de Roo and de Jong (2016), published with the following title: Does the expansion of a motorway network lead to economic agglomeration? Evidence from China.

narrow the coast-inland gap is therefore an acute question for the Chinese administration. Government officials have been wrestling with this problem for many years. For instance, with the implementation of the 'Western Development Strategy' in 1999 (Yao and Ren, 2009), the central government significantly stepped up its investment in public infrastructure, particularly in the construction of the road network in western regions. From 2000 to 2010, a total of 874,984 *km* of new roads (including motorways and paved roads) were built in western China, which has greatly improved interregional transportation conditions in western regions (Ministry of Transportation, 2011; SSB, 2001-2011a). The benefits of these transport infrastructure investments have mainly been verified in empirical studies, which report a positive generative effect of transport investment on economic growth (Hong et al., 2011; Liu et al., 2010; Yu et al., 2012, 2013). However, few studies have provided an answer to the question whether the improvement in roads has helped reduce China's spatial disparity. This might be because evidence of an impact on spatial inequity is hidden when the economic effect of transport investment is demonstrated on the national or regional scale (Holl, 2004a, 2007; Teixeira, 2007; Meijers et al., 2012).

Indeed, at a detailed geographical level, the effect of transport improvement on the local economy is often obscured because some effects induced by transport infrastructure will extend outside the limits of this area, generating spillover effects (Boarnet, 1998). Negative output spillovers can result when mobile factors of production transfer to more developed locations and away from unattractive areas (Boarnet, 1998). It could well be that transport infrastructure investment leads to more economic growth in one place at the expense of less growth or even decline in another, probably due to the migration of production factors induced by the decreasing transportation costs (Vickerman et al., 1996; Boarnet and Haughwout, 2000; Ottaviano, 2008; Banister, 2012). This effect of transport infrastructure on the relocation of economic activities has been identified as the 'distributive effect' (Banister and Berechman, 2001; Lopez et al., 2008; Meijers et al., 2012).

A greater understanding of this distributive effect is essential given that balancing the spatial distribution of economic development resulting from transport facilities development is often a major rationale for investment decisions (Chandra and Thompson, 2000; Holl, 2004; Banerjee et al., 2013; Roberts et al., 2012). Much of the evidence for the existence of such a distributive effect has been obtained from developed countries in recent years, such as Spain (Holl, 2004a, 2007; Lopez et al., 2008), Portugal (Teixeira, 2006; Holl, 2004b), the Netherlands (Meijers et al., 2012; Louw et al., 2013) and the US (Funderburg et al., 2010). For instance, Lopez et al. (2008) explored the impact of transport infrastructure investment on the spatial distribution of accessibility in Spain and found that regional disparity has increased due to rail infrastructure. Holl (2004a, 2004b, 2007) examined the impact of road infrastructure on the location and relocation of firms from Spain and Portugal, and the results showed that new motorways affected the spatial distribution of manufacturing establishments, but the impact differed across sectors and space. Some of these studies of European countries also confirmed an inverted U-shaped relationship between transport improvement and economic concentration, as predicted by the theoretical models of New Economic Geography (Fujita and Thisse, 2002; Ottaviano and Thisse, 2004; Ottaviano, 2008). For instance, Teixeira (2006) reported empirical evidence of a bell-shaped relationship between transport costs and agglomeration in Portugal. Holl (2004a) examined the impact of road infrastructure on the relocation of firms from Spain, and found that the new road infrastructure appeared to facilitate economic concentration which later on was followed by geographic dispersal. For emerging economies, Bird and Straud (2014) measured the impact of the road network on Brazil's growth and the spatial allocation of population and economic activity, and revealed a dual pattern of spatial development (the main centres in the South and the emergence of secondary economic centres in the less developed North) induced by road improvement.

To summarize, most of these studies confirmed the existence of a distributive effect of transport infrastructure in EU countries or the US. However, to our knowledge, there have been very few empirical studies investigating this distributive effect of transport infrastructure in China, despite China having invested heavily in its transport facilities in recent years.

The objective of this paper is to advance our understanding of the role of transport infrastructure planning in China's economic geography. We therefore study how and to what extent motorway network contributes to the agglomeration and dispersal of economic activity across Chinese regions. Furthermore, to highlight the role of road infrastructure in narrowing China's spatial inequity, we also separately evaluate the impact of transport facilities on economic agglomeration or dispersal in China's lagging western areas. This paper provides a thorough analysis of current transport investment policy based on our empirical findings, the results of which could be very significant for China's future transport-infrastructure investment policy. Specifically, we explore:

A) *To what extent and in which direction the spatial patterns of economic distribution in China have changed by virtue of motorway network improvement.*

B) *Whether the relationship between road improvement and economic concentration is bell-shaped, as predicted by New Economic Geography (Fujita and Thisse, 2002).*

C) *Whether motorway infrastructure construction in the lagging areas has contributed to China's spatial equity.*

To this end, we conducted analyses using panel data for Chinese municipalities covering the period 2000 to 2010, during which

Chinese road infrastructure expanded rapidly. This paper differs from earlier studies in three important ways. First, we use data from more-detailed geographic units (municipal level). Geographically detailed studies can reveal spatial distributive patterns, as these tend to be lost at the aggregated scale (Banister and Berechman, 2000; Holl, 2007). Second, we evaluate the distributive effect of motorway network in the poor western regions separately to confirm the impact of transport infrastructure on China's inequity. Third, we apply a computer-simulation method to better forecast the transport-agglomeration nexus in the long run in China.

The rest of the paper proceeds as follows. The next section describes the development of the motorway network and the evolution of spatial distribution patterns of economic activity in China. Section 5.3 introduces the model, variables and data for an empirical contribution on the distributive effects of road infrastructure in China. Our empirical results are reported in Section 5.4, along with a detailed discussion. We end with concluding remarks and a number of suggestions for future planning and policy design.

5.2. Transport improvement and changes in spatial development patterns in China

5.2.1 Motorway network extension in China

Transport infrastructure has played an instrumental role in China's 'growth miracle'. Out of all the infrastructure sectors, the effort to improve the country's roads has received the strongest impetus and investment from the Chinese government since China's economic reform. Take highway construction, for instance. In the early 1990s, China's motorway network was basically non-existent (147 *km* in 1989); the first highway (Hu-Jia) was only completed in October 1988

(China Transportation Statistical Yearbook, 2001). Since then, China has witnessed dramatic development in its motorway construction. By 2000, the total Chinese highway transportation network had increased to 16,314 *km*, making it the third largest highway network in the world (China Transportation Statistical Yearbook, 2001). The principal motorway network has been largely completed, linking the main transportation hubs such as Beijing, Shanghai and Shenyang. The regional density and overall highway coverage has also been optimized.

Undoubtedly, China witnessed a considerable road-building boom from 2000 to 2010. The tenth Five-Year Plan (2001–2005) saw the completion of 24,691 *km* of highways, which was 1.5 times the combined length of all the highways constructed under the seventh to ninth five-year plans (1985–2000). During the eleventh Five-Year Plan (2006–2010), a total of USD 1586.5 *billion* was poured into transport network construction[31]. Since 2000, China's motorway network has been growing at an average of 20 percent per year. In doing so, the country has moved to second place globally in terms of motorway network (96,200 *km* in 2012), only behind the US. All provincial capitals, autonomous municipalities and major cities have been linked, as shown in Figure 5-1. The accessibility of Chinese cities has been much improved.

Lagging western China is the focal point in the construction of this network, with both the number of new projects and the total mileage under construction there being much higher than the national average (Lin, 2010). Indeed, during the period 2000–2010, the average rate of motorway growth in the western region stood at 15.9 percent, while the rate in the eastern and central regions was only 4.7 and 6 percent respectively[32]. Both central and local government hope

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[31] Data are collected from China Statistical Yearbook (2001-2011).

[32] Authors' calculation based on data from China Transportation and Communication

the rapidly improving road network will spur the economic development of the western region.

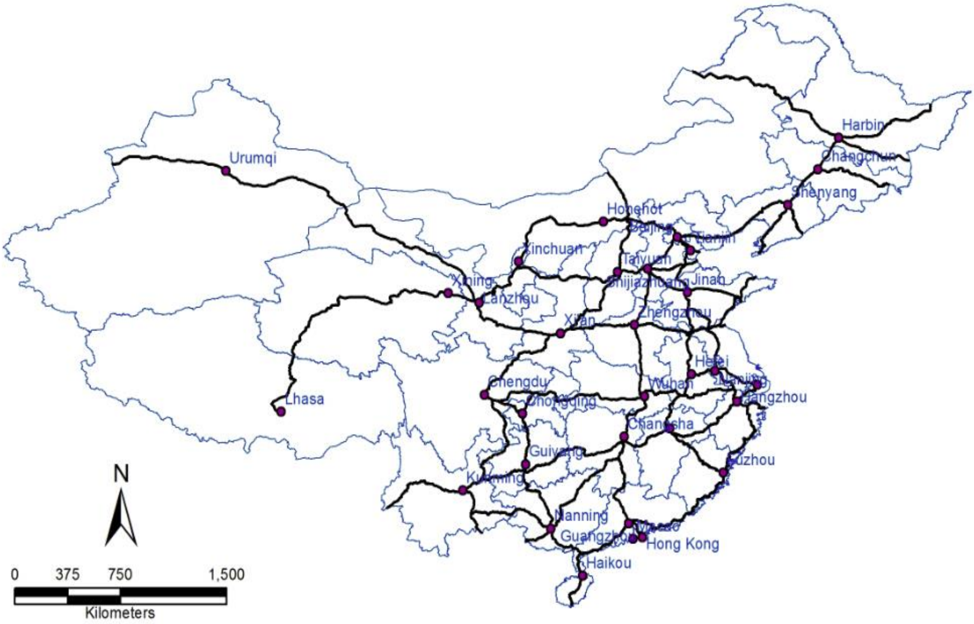

Figure 5-1. The Chinese motorway network in 2010

Source: Highway network map data is collected from China Foundational Geography System.

5.2.2 The evolution of a spatial economic development pattern in China

We will start with a brief introduction of the evolution of the regional distribution of GDP in People's Republic of China since its foundation.

Yearbook, 2001–2011.

Table 5-1. Changes in GDP and the share of Chinese regions

		1952	1980	1990	2000	2010
North-coastal	GDP	104.98	703.77	1702.95	5628.32	19277.70
	Share	17.84%	17.84%	17.47%	18.56%	18.81%
	Growth rate	-	7.03%	9.24%	12.70%	13.10%
East-coastal	GDP	109.60	773.83	1989.13	7206.99	24826.04
	Share	18.62%	19.61%	20.41%	23.77%	24.23%
	Growth rate	-	7.23%	9.90%	13.74%	13.17%
South-coastal	GDP	42.25	335.20	1080.40	4369.81	14929.29
	Share	7.18%	8.50%	11.08%	14.41%	14.57%
	Growth rate	-	7.68%	12.42%	15.00%	13.07%
Centre	GDP	146.17	890.75	2133.42	5938.66	19830.14
	Share	24.83%	22.58%	21.89%	19.58%	19.35%
	Growth rate	-	6.67%	9.13%	10.78%	12.81%
Northeast	GDP	84.00	552.80	1199.24	2874.59	9628.57
	Share	14.27%	14.01%	12.30%	9.48%	9.40%
	Growth rate	-	6.97%	8.05%	9.14%	12.85%
West	GDP	101.60	688.76	1641.44	4305.03	13985.16
	Share	17.26%	17.46%	16.84%	14.20%	13.65%
	Growth rate	-	7.07%	9.07%	10.12%	12.50%

Source: Authors' calculation based on data from the China Six Decades Statistical Compilation (2009) and the China Statistical Yearbook (2011).

Note: Here, we define the northeastern region as including Jilin, Liaoning and Heilongjiang. The hinterland of China (Centre) consists of Henan, Jiangxi, Hunan, Anhui, Hubei and Shanxi. The north-coastal region includes Beijing, Tianjin, Shandong and Hebei, and the south-coastal region Fujian, Guangdong and Hainan. The east-coastal region comprises Shanghai, Jiangsu and Zhejiang. The western region consists of Yunnan, Guizhou, Sichuan, Chongqing, Guangxi, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Inner Mongolia.

Table 5-1 reports the changes in GDP share in China's main regions from 1952 to 2010. As the table shows, the spatial development pattern did not change significantly from 1952 (the foundation years of the People's Republic of China) to 1978 (the year of economic reform). However, as China's growth miracle started in the coastal regions, these regions' share of aggregate GDP significantly increased from the 1980s onwards, and especially after 1990. This obviously meant that the shares of the other interior regions declined. Figure 5-2 also shows that economic activity in this decade continued to grow increasingly concentrated and expanded more rapidly in the coastal regions. Accordingly, the pronounced disparity between the coastal and inland provinces in China has grown further since economic reform.

In part (a) of Figure 5-2, the Choropleth mapping shows the absolute output changes between 2000 and 2010 (the values range between 0.43-946.14 billion yuan). Obviously, the coastal areas have experienced a higher GDP growth during the last years. As a result, more and more economic activities gathered in the eastern region. Part (b) of Figure 5-2 displays the spatial distribution of GDP at the municipal level in 2010. Two clear features of the spatial distribution in China's current economic development can be seen on this map. First, China's economic activities are mainly concentrated in the eastern coastal region, such as the Yangtze River Delta, the Pearl River and the Bohai Baky region. Second, the clusters of economic activity are like stairs descending from the higher eastern China to the lower western China. Thus, the core (coastal eastern region) to periphery (interior central and western region) pattern in the distribution of economic development is obvious in China.

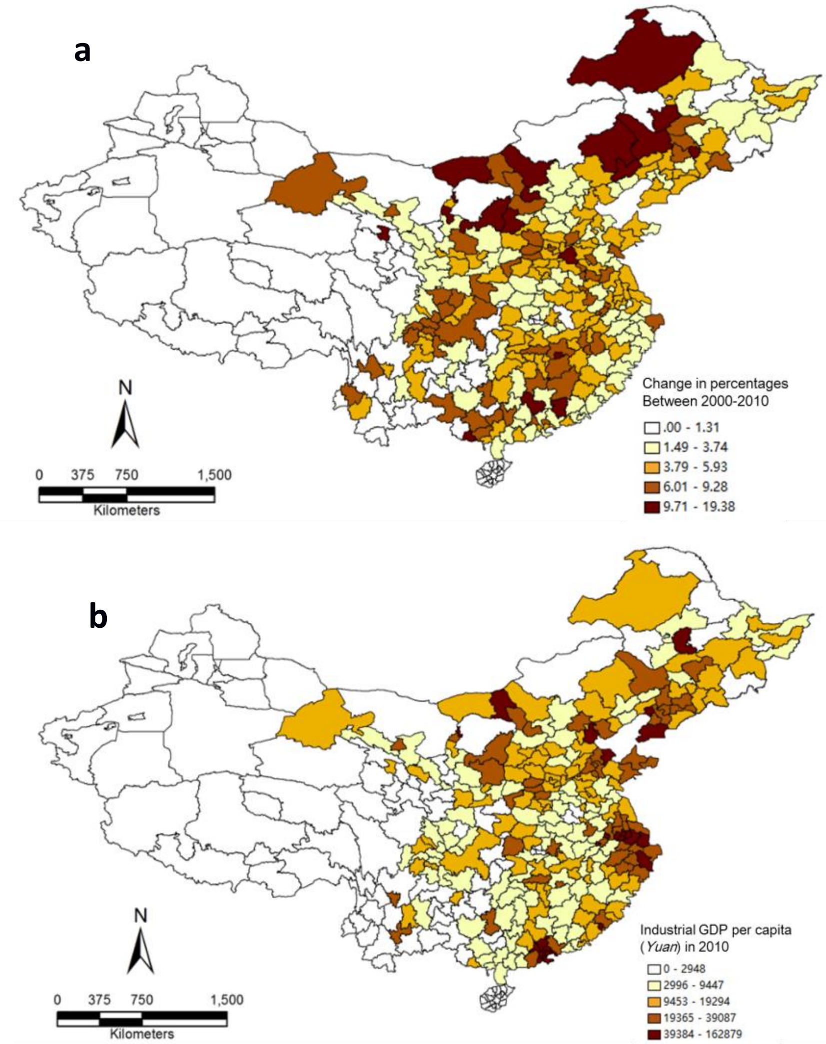

Figure 5-2. (a) Changes in China's industrial geography 2000-2010; (b) China's industrial geography in 2010

Note: Part (a) presents the change in percentages (%) of industrial GDP between the periods of 2000-2010 and part (b) shows municipal industrial GDP per capita at current price in *Yuan*. The data is from the authors' own calculations based on data from the China City Statistical Yearbooks (2001, 2011). Map data is from the China Foundational Geography System.

However, the reasons for these patterns of geographic agglomeration are complex, since they are the outcome of a variety of natural, policy and other factors. For instance, China has long followed a biased development policy, the so-called 'Coastal Priority Development Strategy' since the beginning of economic reform. Concentration of both capital and human resources in the eastern (coastal) provinces was encouraged at the initial stage of economic reform. Meanwhile, the large demand induced by exportation is also a potential reason for the industries concentration in the coastal provinces. By contrast, in the western region, most provinces have suffered from drought, difficult climatic and geographic conditions, which resulted the production factors migrating to much better and developed locations.

Focusing on our main research goal, a central question is whether motorway network improvements lead to a higher concentration or dispersal of economic activities in China. The New Economic Geography theory suggests that transport infrastructure improvement could lead firms to relocate due to changes in accessibility. This relocation could lead to more concentration and hence regional divergence (Fujita et al., 1999; Holl, 2004a, 2004b, 2007). The answer to this question is important for investment policies aiming at balanced development across Chinese regions.

5.3. Methodology and data

5.3.1 Model Specification

In order to analyse the role of motorway networks in the process of agglomeration or dispersal of China's economic activities, a detailed geographic analysis follows in this section.

We describe the spatial development pattern by location quotient (*LQ*), which is a way of quantifying concentrated industries or clusters in an area compared with the national pattern (average). The *LQ* measures the level of industrial agglomeration in one region (Liu, 2008), and the *LQ* in region *i* is calculated as follows:

$$LQ_i = \frac{IY_i / Y_i}{IY / Y}$$

Where *IY* is the industrial GDP and Y indexes the total GDP in the whole nation. Given the focus of this paper, motorway network density (*Road*) and education attainment level (*Edu*) are regarded as the main explanatory variables, while other agglomeration determinants could also be distinguished following Holl (2004, 2007a) and Meijers et al. (2012). These include measures of market demand -which can be proxied using municipality population (*Pop*) and GDP per capita (*GDP*), market accessibility potential (*ACC*)[33], wage costs (indexed by the average wage, *Wage*), and measures of economic agglomeration (proxied using degree of specialization, *Spe* and the amount of exports, *Exp*). As a result, a basic empirical model can be constructed as follows:

$$LQ = f(\mathrm{Road}, \mathrm{Edu}, \mathrm{Pop}, \mathrm{GDP}, \mathrm{ACC}, \mathrm{Wage}, \mathrm{Spe}, \mathrm{Exp})$$

In addition to these main explanatory variables, several regional dummies were added to the model to control for the geographic difference between municipalities, including a provincial capital dummy to distinguish the political centre from other municipalities, a resource-oriented city dummy to highlight this type of city's development characteristics and a coastal city dummy to emphasize its locational advantage[34]. In 2008, 38 percent of the RMB 4 *trillion*

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[33] Market accessibility potential reflects the size of the potential market area a given location has access to after taking into account the cost of overcoming distance.

[34] The lists of provincial capitals, resource-oriented cities and coastal cities are not provided in this paper due to word limits, but are available from the authors upon request. The list of resource-oriented is collected from 'Planning for the Sustainable Development of National Resource-oriented Cities', which is available on line:

yuan Chinese stimulus package was earmarked for infrastructure construction. Thus, a dummy variable to cover the 2008–2010 period was also added to control for the temporary shocks induced by policy changes. Furthermore, in order to test the theoretical hypothesis of an inverted U-shaped relationship between transport improvement and a geographic agglomeration of economic activities, a quadratic road network term was included in the model.

Moreover, regarding the small size of the spatial units (especially in the eastern region) considered in this paper, we also added a spillover variable of motorway network ($W * Road$), in order to control for the effects of this key factor on spatial concentration of industries driven by transport improvement in surrounding units. A binary contiguity matrix is used to construct the spatial weighted matrix (W_{ij}), which assumes only contiguous provinces can influence each other[35]. Therefore, a symmetric spatial matrix of the 274 Chinese municipalities can be obtained based on our observations.

Thus, the following empirical model based on the panel data considering the fixed effect can be estimated:

$$\begin{aligned} LQ_{it} &= \nu_i + \xi_t + \beta_{1i} Road_{it} + \beta_{2i} \log Edu_{it} + \beta_{3i} \log Pop_{it} + \beta_{4i} \log GDP_{it} \\ &+ \beta_{5i} ACC_{it} + \beta_{6i} \log Wage_{it} + \beta_{7i} Spe_{it} + \beta_{8i} Exp_{it} + \beta_{9i} W_{ij} Road_{it} \\ &+ \beta_{10i} Road_{it}^2 + \gamma_{it} Dummies_{it} + \varepsilon_{it} \end{aligned}$$

Here, all the explanatory variables are defined as above; ε_{it} is the stochastic error; and ν_i and ξ_t are municipality- and time-specific

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http://wenku.baidu.com/link?url=iniWQy8fx3Lkud0Bi1CvHlVJwmf2Sc1DmRjUJ_3fqyZhwL9O_jBO9z8S0ilU9rkYpL30U--jssTfQ9XY5zd00ct9t_G6jPv3-l7J61RBiQK

[35] In this study, we adopt a binary contiguity matrix to construct the spatial weighted matrix: w_{ij} equals to 1 if the city *i* has a border with city *j* otherwise equals to zero, and $\sum_{j=1}^{N} w_{ij} = 1$.

parameters, respectively. The former takes into account unmeasured characteristics of municipalities and the latter is introduced to control for temporary shocks or policy changes that might have affected all municipalities at the same time.

5.3.2 Data collection and description

This study uses data from multiple sources, including China Regional Economic Statistical Yearbooks and the China City Statistical Yearbook from 2001 to 2011. Complementary data was obtained from the Provincial Statistical Yearbooks from 2001 to 2006. Geographic measures were constructed using ArcGIS software based on the basic map data from the National Fundamental Geographic Information System of China. This paper follows Head and Mayer (2006)[36] in using GIS data to calculate market accessibility. Since the road network in China is quite dense, the distance between an arbitrarily defined centroid and the nearest road is not a meaningful measure of access to roads. Following Banerjee et al. (2013), our proxy for access to roads is instead the density of roads in each city. Therefore, we compute road density by taking the total length of highways (multi-lane highways) in each city and dividing it by its land area. The average educational attainment level is proxied using the average years of schooling in the population over six years old. The data on investments, wages and GDP are converted to constant 2000 prices. Due to limited data availability, data on education, export and

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[36] This paper follows Head and Mayer (2006) in using the 'geographic center index' to index the potential market accessibility, which can be calculated by $GC_i = \ln \sum_{i \neq j} d_{ij}^{-1}$, where d_{ij} is the physical distance between region *i* and region *j*.

specialization are chosen at the provincial level.

The autonomous regions of Tibet and Xinjiang are special areas in China, subject to different policies because of their location and religion. The construction of infrastructure in these areas is guided by different considerations from those that guide infrastructure investment in the rest of China. We therefore exclude these two autonomous regions from our sample for both economic and non-economic reasons. Hainan province is an island, which cannot be connected to the other provinces by a road network, so samples from Hainan province are also excluded. Having excluded some municipalities due to missing data, we end up with a data panel of 274 municipalities for the period 2000–2010. Together, these consist of a total of 3014 observations in our empirical study. Table 5-2 provides a basic statistical description of the main variables in our empirical study.

Following NEG theory, we provide the expected signs for the main explanatory variables. Market demand is expected to positively affect economic concentration because higher demand is very attractive to the industry (Holl, 2007). Potential market accessibility is the key indicator in the process of economic clustering, the positive effect of which has been widely accepted for theoretical and empirical reasons (Lopez et al., 2008; Puga, 2008). We expect the amount of exports to have a positive effect on industrial concentration due to higher market demand. The expected signs for infrastructure (transport and education) are uncertain, because theoretical models indicate that the role of these variables in explaining geographic concentration correspond with the level of economic development in a region (Holl, 2007; Ottaviano, 2008; Puga, 2008). The higher average annual wage can disperse industry due to high costs (Fujita et al., 1999), but at the same time, higher wages mean greater market demand: the impact of a higher wage is therefore not clear a priori, because it can motivate firms to move away (because of higher costs) or attract new firms to the region (because of higher market demand).

Meanwhile, the effect of specialization is also unsure: on the one hand, the traditional industrial areas are prone to attract more industry to a region because of the home market effect, but on the other hand, more industry in one area means fiercer industrial competition (Fujita and Thisse, 2002).

Table 5-2. Statistical description of the main variables

Variables	Description	Max.	Min.	Mean	Std. dev	Expected sign
Population size (Pop)	The total population in a city (10,000s)	3303.45	39.17	427.93	292.79	+
GDP per capita (GDP)	The total GDP in a region divided by local population (10,000 yuan)	14.99	0.11	1.46	1.26	+
Road density (Road)	Total road mileage in a region divided by its land area	3.41	0.01	0.56	0.40	+/-
Educational level (Edu)	Average years of schooling per person	11.52	6.41	8.19	0.60	+/-
Potential market accessibility (ACC)	Index of potential market accessibility	5.23	1.02	3.41	0.45	+
Export (Exp)	The amount of exports in each municipality (10,000 yuan)	4531.91	1.12	404.21	837.07	+
Specialization (Spe)	Share of manufacturing employment in total regional employment	0.52	0.11	0.26	0.09	+
Average wage (wage)	The average annual wage in one area (10,000 yuan)	7.27	0.44	0.87	0.30	+/-

Note: Here we measure the average years of schooling in the total population aged six and over using $EL = \sum_{1}^{5} p_i NY_i$, where p_i is the share of population with education level *i*, and NY_i is the average years of schooling associated with the i^{th} education level. More details are available from the authors.

5.3.3 Estimation Strategy

In order to implement a convincing empirical test, the following econometric issues are taken into account.

The first concern is related to the problem of potential multicollinearity of the explanatory variables. A symmetric matrix of correlation coefficients can be constructed[37]. The results show that the ordinary correlation coefficient between *Spe* and *Export* is 0.77, higher than 0.5, indicating the existence of multi-collinearity between independent variables in our empirical model. Econometric theory tells us that differencing variables can reduce the multi-collinearity in one model (Pedroni, 2007). Thus, we choose differenced *Exp* instead of the original series. The correlation coefficient between *Spe* and *Diff.(Exp)* is 0.02. Thus, the variables of specification and (differenced) exports can be estimated in the same model.

Secondly, in estimating the impact of transport improvement on industrial concentration, endogeneity may arise because it is not unreasonable to assume that the State prefers to build more roads in more developed areas. So as to ensure that results are not driven by reverse causation, our empirical estimation relies on the Generalised Method of Moments (GMM) method for dynamic panel models

[37] We did not present the correlation coefficients matrix due to the words limitation, however, more calculation details are available from the authors upon request.

(Arellano and Bover, 1995; Blundell and Bond, 1998), which combines a system of equations that include regressions in differences and regressions in levels. The Generalized Method of Moments (GMM) estimators are generally designed for situations with 'small T, large N' panels, meaning few time periods and many individuals, with independent variables that are not strictly exogenous, which perfectly fit our case. Although a first-differenced GMM (Arellano and Bond, 1995) could be regarded as an alternative, the system GMM estimator that combines moment conditions obtained from equations in first differences with additional moment conditions exploited from the levels equations can be expected to provide more efficient estimates (Blundell and Bond, 1998; Jiwattanakulpaisarn et al., 2010). For GMM estimation of the differenced equations, we use restricted sets of instruments so as to avoid overfitting problems. Two specification tests including the Arellano–Bond test for serial correlation and the Sargan test for overidentifying restrictions are employed to assess whether the instruments are exogenous and thus valid to be used in the system GMM estimation.

Moreover, we transferred the natural logarithm form for some variables in our estimation (population size, GDP per capita, Export and Average wage) in order to narrow the absolute value of the original data, which is convenient for the further estimation. This transformation could not significantly affect the regression results (no effect on signs at all).

Finally, in order to check the robustness of our empirical results, an OLS estimation was also adopted since in these models, the relevant regional dummies could be included simultaneously.

5.4. Results and discussion

5.4.1. The distributive effect of transport infrastructure

Table 5-3 provides both Sys-GMM and OLS estimation results for Equation (5-3) for all samples and for poor areas. Starting with the result for all samples in columns 1-4, most variables have the signs theoretically predicted. The positive signs for GDP per capita show that market demand is an important factor in the clustering of economic activity. This would seem to makes sense, because if the purchasing power in one area is much higher than in neighbouring areas, more industry will want to relocate to this area due to the greater demand and larger market. Consistent with previous studies (Holl, 2004a, 2007; Lopez et al., 2008), the positive impact of potential market accessibility can be verified in our study (the coefficient is statistically significant and positive). The significantly positive regressor of average wage can be obtained, suggesting that the relatively higher wage in the coastal region has not constrained the development of Chinese firms until now. The greater market demand induced by the higher wage led more industries to relocate. The regression coefficient of export is not significant, probably because the share of international business is limited compared to China's huge domestic market demand. We also found that the traditional industrial areas (higher specialization) do not attract more industry to a region because two opposing effects (home market effect and higher competition) cancel each other out in practice (Fujita and Thisse, 2002).

Interestingly, as a typical social infrastructure, education has very different distributive effects on geographic concentration. On the national scale, the level of educational attainment has no stable impact on economic concentration (the sign of coefficient turns out not to be negative when dummies are added), but a positive effect on the lagging areas can be observed, as shown in columns 5 and 6 of Table 5-3. This finding conflicts with Liu (2008), probably because of methodology we adopted in this study (the potential endogeneity of independent variables has been conquered by Sys-GMM), and also because of the data-we used average schooling years as a proxy for education attainment level, which we consider more appropriate than literacy rate.

Table 5-3. Main estimation results

	All samples				Poor regions	
	Sys-GMM		OLS		Sys-GMM	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
LQ(-1)	0.485(17.23)***	0.552(17.64)***	-	-	0.527(50.12)***	-
Road (Road)	0.121(5.75)***	0.709(5.76)***	0.102(6.40)***	0.208(5.07)***	-0.571(-11.62)***	-0.163(-2.12)**
Education (Edu)	0.065(3.15)***	0.093(4.29)***	-0.047(-4.44)***	-0.046(-4.39)***	0.016(1.18)	0.085(2.15)**
Population (Pop)	0.045(0.14)	-0.029(-0.09)	0.006(0.62)	0.001(0.14)	0.189(0.86)	0.005(0.16)
GDP per capita (GDP)	0.137(3.40)***	0.204(4.69)***	0.335(26.20)***	0.331(25.73)***	0.463(16.79)***	0.385(8.55)***
Potential market accessibility (ACC)	0.472(5.24)***	0.249(3.42)***	0.351(6.36)***	0.324(4.63)***	0.201(1.42)	0.293(2.75)***
Export (Exp)	-0.001(-0.73)	-0.011(-1.06)	-0.026 (-1.12)	-0.029(-1.24)	0.058(5.50)***	-0.086(-1.14)
Specialization (Spe)	0.417(3.01)***	0.086(0.35)	-0.197(-2.48)**	-0.215(-2.70)***	-0.304(-1.88)	0.454(0.65)
Average wage (Wage)	0.461(5.99)***	0.502(5.90)***	0.090(3.27)***	0.087(3.15)***	0.911(11.19)***	0.034(0.28)
W*Road	0.104(6.32)***	0.039(4.72)***	0.163(2.98)***	0.117(4.01)***	-	-

Road²	-	-0.352(-4.69)***	-	-0.062(-2.79)***	-	-
Dummy coastal	-	-	-0.037(-2.22)*	-0.039(-2.34)**	-	-
Dummy capital	-	-	-0.256(-12.16)***	-0.254(-12.10)***	-	-0.239(-3.52)***
Dummy resource	-	-	0.122(10.45)***	0.122(10.51)***	-	0.168(4.12)***
Dummy period	-	-	-0.075(-5.47)***	-0.078(-5.66)***	-	0.012(3.21)***
Observations	2466	2466	2740	2740	495	550
Sargan test	[0.17]	[0.35]	-	-	[0.14]	-
AR(2)	[0.53]	[0.62]	-	-	[0.51]	-
Effects specification	Cross-section fixed	Cross-section fixed	No effects	No effects	Cross-section fixed	No effects
R^2	-	-	0.42	0.39	-	0.36

Note: ***, **, * denotes statistical significance at 1%, 5% and 10% separately; t-statistics appears in parenthesis; p-statistics are shown in the square brackets. We define poor areas as the cities in the western provinces, including Gansu, Ningxia, Shaanxi, Yunnan, Guizhou, Sichuan, Chongqing, Guangxi and Qinghai. In all estimations, we transferred the natural logarithm form for population size (Pop), GDP per capita (GDP), Export (Exp) and Average wage (Wage) in order to facilitate further estimation.

With respect to the regional dummies, some conclusions can be drawn from our empirical study. The coefficient of the resource-oriented municipalities dummy is significantly positive, suggesting the concentration of economic activity in these areas. This is in line with a fundamental insight from NEG, namely that natural resource endowments are the 'first geography', which provide regions with an initial comparative advantage in resource-oriented activities and lead to clustering in these activities (Fujita et al., 1999; Ottaviano, 2008). However, the industries did not cluster in the provincial capitals as we expected, as the provincial capital dummy is found to be statistically insignificant. The effect of this dummy is likely overwhelmed by the impact of other main explanatory variables on economic agglomeration (for instance, assuming that capital cities on average have denser motorway networks and higher education attainment level).

Focusing on the motorway network – the variable we are most interested in – there would appear to be a stable, statistically significant positive relationship between spatial economic agglomeration and road network improvement in China. This finding remains robust no matter which method we adopted or after the introduction of additional dummies, as seen in columns 1-4 of Table 5-3. These results definitely confirm the existence of a distributive effect of transport infrastructure in China, and imply that road infrastructure currently plays an essential role in changing China's spatial development patterns. An improvement in the road network could accelerate the spatial agglomeration of economic activities when all other things being equal. Moreover, the significantly positive coefficients of the spillover effect of motorway network suggest that motorway construction in the neighbouring units also contributes to local industrial clusters.

In order to distinguish between the motorway networks in developed and less-developed regions, we also ran the empirical model for the lagging areas separately. The results are reported in columns 5 and 6 of Table 5-3. However, the coefficient for the road infrastructure changed to significantly negative, suggesting a loss of industry in these regions due to improvement to the motorway construction. This can help explain the puzzling widening gap between coastal and western regions in the last decade in the face of the considerable investment in transport facilities in poorer western provinces.

These findings may disappoint Chinese government officials who believe that investment in transport infrastructure is a key policy tool to stimulate growth and reduce regional disparity. In contrast, our empirical results show that improvement in transport facilities lead to greater concentration, mainly in the coastal provinces, as discussed in Section 2. Contrary to the expectations policymakers have, the undeniable coastal-interior disparities have grown further since the poor western areas have become more accessible.

However, it is worth noting that the relationship between these two variables is complex and not constant over time. One strand of literature connects the evolution of the spatial distribution of industries to the various stages of economic development (Ottaviano and Thisse, 2004; Ottaviano, 2008). We will therefore examine below how the transport-agglomeration nexus changes with better road infrastructure endowment.

5.4.2. The bell-curve of spatial development

The bell-shaped relationship between the degree of spatial concentration of economic activity and transport costs predicted by NEG theory has been empirically observed in many studies (Combes and Lafourcade, 2001; Holl, 2007; Teixeira, 2006). These authors argue that a high degree of core concentration occurs in the early phases of economic growth along with a widening rich-poor wage differential (Fujita and Thesis, 2002), and that as development proceeds, spatial de-concentration of industries and a narrowing wage differential follows. The emergence of a core-periphery structure is therefore expected to be followed by a phase of interregional convergence (Teixeira, 2006).

To examine this argument in the context of China, we added a quadratic road network term to our empirical model to examine the presence of this kind of bell-shaped relationship in China. We found a non-linear link between economic agglomeration and the road networks in China, as an inverted U-shaped relationship could be discerned from the positive sign of the road network term and the negative sign of the quadratic term from our regression results (columns 2 and 4 of Table 5-3). When the geographic concentration is relatively low, improvement in the road network appears to accelerate the spatial agglomeration of economic activity, whereas when the concentration is high, decreasing transportation costs help industries disperse to the peripheral regions. This phenomenon is in line with NEG theory models. However, to our knowledge, this paper is the first to report this result for the People's Republic of China.

In order to assess the possible implications of the planned transport policy, we used MATLAB to simulate the degree of concentration and fit for the transport-concentration nexus, as displayed in Figure 5-3. In the short term, the fitted curve shows that economic agglomeration is positively associated with improvement in the road network (the peak value of motorway network density is 1.52). However, if we forecast this curve for the long term, we find that the pattern comes to resemble an inverted U. Improvement in the road network (reduction in transport costs) is likely to cause substantial spatial dispersal of economic activity when the transport costs fall below a critical level. The fitted result of the quadratic function is satisfactory (the coefficient of the quadratic term has a *p*-value of 0.03, and R^2 is 0.37).

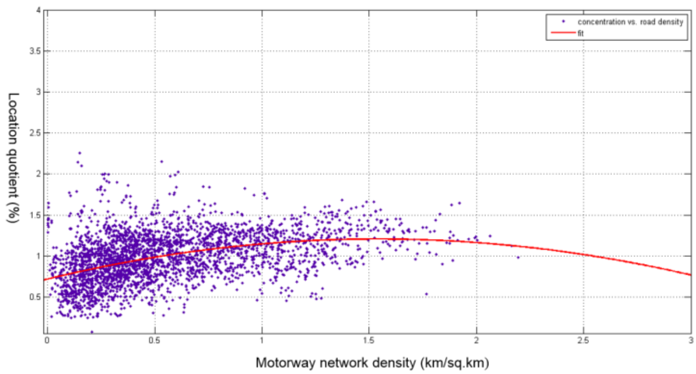

Figure 5-3. Fitting the road improvement-agglomeration nexus in the long term

Note: The x-axis denotes road network density (negatively associated with transportation cost), and the y-axis represents the location quotient, which measures the degree of economic concentration. We simulated the road-agglomeration nexus using quadratic polynomial fitting.

Some European scholars also confirmed this bell-shaped relationship between transport costs and agglomeration by examining the distributive effects across several sub-periods or in simulation, as discussed in the introduction (Teixeira, 2006; Holl, 2004a). The countries they examined – such as Spain and Portugal – witnessed the dispersal of industries before 2010 because of their relatively higher developmental stage. China, however, will need to wait several decades for this dispersal to occur. If we look at the simulation results from Figure 5-3, the massive dispersal looks likely to occur when the road network density is approximately three times greater than its current level. This is obviously an ambitious target, especially at a time when growth in China has already slowed in pace. Moreover, wages in the developed coastal regions are not very high compared with those in interior regions, mainly because of the seemingly 'endless' supply of cheap labour in China. The advantage of lower wages is expected to be too small to induce firms to relocate outside East China for a long period to come (Yu et al., 2013). It therefore seems likely that the spatial concentration and inequality in China will further intensify in the coming decades.

5.4.3. Transport infrastructure investment policy in China

In order to highlight the role of road infrastructure in China's economic development and regional disparity, we performed a further analysis of transport investment policy based on our empirical findings, as represented in Table 5.4.

Although policymakers and planners in China have neglected the impact of transport infrastructure on economic activity agglomeration in the decision-making process, the distributive effect of transport infrastructure is by no means insignificant. Our empirical results show that road infrastructure will increase the agglomeration of economic activities, thus widening coastal-inland disparity. Moreover, the negative impact of transport facilities on poor regions also indicates the outflow of industry over the last ten years. Accordingly, the increased industrial agglomeration in the coastal areas has resulted in growing spatial inequity in China. Nevertheless, we should also note that the higher degree of geographic concentration will lead to a higher national economic growth rate due to industrial specialization and technological innovation (Fujita and Thisse, 2003; Liu, 2008).

As the national government has invested heavily in road and railway construction in underprivileged West China, it is not surprising that more industry has relocated to the more-developed areas in recent decades. In other words, the nation has achieved a higher economic growth rate at the expense of widening regional disparity. Current transport investment policy therefore appears to be faced with a trade-off between *spatial efficiency* (greater geographic concentration of industry and a higher growth rate) and *spatial equity* (more-even spatial distribution of economic activities) (Zheng and Kuroda, 2013).

Table 5-4. Transport infrastructure investment policy analysis

Aim of investment policy	Economic growth	√
	Relocation of economic activity	×
	Spatial equity	√
Result of investment policy	Economic growth	Higher growth rate with increased concentration of economic activity Modest growth in economic dispersal
	Relocation of economic activity	At the national level, transport infrastructure improvements leads to greater geographic concentration For the lagging areas, transport facilities facilitates spatial dispersal
	Spatial equity	In the short term, greater concentration brings greater economic growth with a widening gap between rich and poor In the long term, the inverted U-shaped relationship can be verified
Investment policy design	Spatial growth and equity	Trade-off between spatial growth and spatial equity

From a national perspective, transport infrastructure construction is necessary for China's growth goals; however, reducing urban-rural, coastal-inland disparity is another key policy objective of the Chinese government, as important as economic growth in recent years. It is therefore necessary for policymakers to intervene in the economic concentration process to narrow spatial inequality among Chinese regions. For instance, investment in education could counteract the trade-off between spatial equity (education did not exhibit a significant impact on economic concentration in our empirical findings) and spatial growth (the importance of education has been underlined in many studies, such as Fleisher et al., 2010). In particular, investment in education in poor areas could facilitate agglomeration in these regions, which would help strengthen these areas. From this perspective, improving education could be a valuable strategy for decision-makers wishing to promote spatial equity in China.

5.5. Conclusion

Transport infrastructure has played an instrumental role in the ascent of the China to global economic power status. The generative effects of transport infrastructure development measured on the macro-spatial scale often obscure distributive effects on the highly localized micro-spatial scale (Holl, 2007; Meijers et al., 2012). In this paper, we focused on such distributive effects and used municipal-level panel data to empirically estimate the role of motorway network in the evolution of China's geographic distribution.

Overall, this study confirms the existence of such distributive effects of road infrastructure in China, suggesting that an improvement in transport facilities would accelerate geographic concentration on the national scale, which means greater growth according to the NEG theories (Fujita and Thisse, 2003). Even though this belief is widely supported by the observations of developed countries during the developmental process, very limited evidence on the developing countries have been provided. The findings of our study provides important implications of policy design for other emerging countries like China. To achieve the goal of fast growth, transport-oriented development strategy seems to be one possible solution to the developing countries at the take-off stage such as India and Brazil, with empirical support indicating that transport infrastructure could generate increases in output and reshape economic activities as well.

Moreover, our empirical results show the impact of the motorway network on economic agglomeration in the lagging western areas is negative, indicating a loss of industry in these poorer regions during the observed period. This means that the less-developed regions in China have become relatively more peripheral due to their increased accessibility by road, which is probably contrary to the original intention of the policymakers (Banerjee et al., 2013; Yu et al., 2013). Furthermore, consistent with the predictions of NEG models (Fujita et al., 1999; Ottaviano, 2008), the bell-shaped relationship between transport improvement and geographic agglomeration can be observed in our simulation of China, indicating that industry will spread to peripheral areas if transport costs are lowered sufficiently. However, this dispersal will require some time, due to China's developmental stage and unique social features. During this period, investment in transport infrastructure would allow more firms to further concentrate in the better-developed East China, which would widen the spatial inequity in China. These findings have implications for China's long-term policy in terms of public funding and negative externalities. The result of investment in transport infrastructure represents a trade-off between spatial equity (more even spatial distribution of economic activities) and spatial growth (greater concentration and higher growth rate), while investment in education could offer an alternative to this trade-off (spatial equity and spatial efficiency). Given the political aim of reducing spatial inequity, the appropriateness of the current 'transport-infrastructure-stressed' investment policies in these areas should be questioned, especially for the lagging western areas (Yu et al., 2013), and investment in education would be strongly recommended, since improved education could stimulate economic growth in China and cause a more even pattern of development across regions.

Chapter 6

Conclusion

6.1 Introduction

Public infrastructure is often mentioned as a key to promoting economic growth and development. This belief has been supported by the observation of rich countries, such as the U.S., Japan and those in Western Europe, where plenty of infrastructures developed during times of rapid economic growth. China has been one of the world's fastest-growing and most important emerging economies in recent decades with good performance of public infrastructure. The open-door policy was implemented in 1978, allowing the inflow of foreign direct investment to the manufacturing sector. Cheap labour and a better than average infrastructure were both required for the export-led growth strategy. With a seemingly unlimited supply of cheap labour from the rural sector, public investment in infrastructure became the keystone in China's strategy. A major focus on infrastructure by the government at all levels thus ensued. Meanwhile, Chinese policy makers face a dilemma, because continued economic transformation has not been equally beneficial across China's major regions. The interior region (near west) and far western regions lag far behind the coastal region in economic progress. Thus, public infrastructures are also regarded as the key political anchor to reducing regional disparity. The availability of an appropriate infrastructure might prove helpful in facilitating communications between provinces and with the outside world. However, the result of investment policy - both for growth and even distribution - was still unexplored.

In line with this debate, we present our main research question in the introduction of this book, "Does investment in public infrastructure contribute to China's growth and to the growing regional disparity?" After extensive research, guided by several sub-research questions, we have synthesized our results here. What did we discover? What did we learn? And are there any implications for China's infrastructure planners and decision-makers? In this concluding chapter, section 6.2 systematically answers the research questions. Section 6.3 raises policy suggestions on the future infrastructure development in China based on the findings in the previous chapters. Finally, section 6.4 presents the research limitation and future agenda.

6.2 Answering Questions

To answer the main question, we put forward four sub-questions in the research process. The first question reveals the causal relationship between transport infrastructure and economic growth at different geographic levels. After that, question two and three explore the exact effect of public infrastructure (transport infrastructure and education) on China's economic growth. Question four focuses on the role of public infrastructure, both of transport infrastructure and education, in explaining the regional disparity.

Is the (growing) regional disparity in economic development within China related to existing spatial inequalities in the distribution of transport infrastructure? Can we establish any patterns of (Granger-) causality between spatial disparities in transport infrastructure and spatial economic development in China and its regions? If so, what is its direction?

Our study shows that both economic activities and transport infrastructure are heavily concentrated in the eastern coastal provinces. The clusters gradually decrease in frequency from higher eastern China (rapid growth, higher incomes per head and a big transport infrastructure capital stock) to the lower western China (slower growth, lower incomes per capita and smaller transport infrastructure capital stock). This indicates that the development of transport infrastructure and regional economic performance are concomitant in China. Thus, the growing regional disparity in economic development within China may be interrelated with the spatial inequalities in transport infrastructure. This finding gives us enough incentive to seek the causality between public transport infrastructure and economic development in China and its three macro-regions.

The empirical results show that at the national level, a unidirectional Granger causality from economic growth to transport investment can be found in China, but no reverse causality from transport investment to growth. For the whole nation, economic growth leads to a growing demand for transport services and fulfills this demand by increasing public investment directly or organizing the large transport projects indirectly (Mu et al., 2011). Meanwhile, the poured transport investment in recent decades does not guarantee China's economic growth. The results of our panel co-integration test show that there is a stable long-run equilibrium relationship between economic growth and transport infrastructure. It indicates that the improvement of transport infrastructure can facilitate China's economic growth, which is in line with the expectations of decision-makers. However, transport infrastructure investment is not the Granger cause of economic growth, which implies, statistically speaking, that regional economic growth is based on other sources than transport investment.

At the regional level, the Granger causal relationships vary across sub-national areas. For the rich eastern region, the bidirectional causality between transport investment and economic growth exists, while a unidirectional Granger causality from economic growth to transport investment can be identified for the less developed interiors (the central and western region). These findings suggest that transport infrastructure development is found not to be an important engine for economic growth in the low-income central and western provinces. An underdevelopment of other complementary factors is a likely reason for a lack of causality running from transport investment to economic growth in these provinces (Zhang and Sun, 2008; Liu and Hu, 2010). It means that an improvement in transport infrastructure alone is not sufficient for stimulating regional growth. China's case shows that ample investments in transport infrastructure do not bring the benefits people expect in the underdeveloped areas.

What is the impact of transport infrastructure on China's economic growth? What is the impact of transport infrastructure investment on economic growth in China's Eastern, Central and Western Regions? Does the regional allocation of transport infrastructure investment help reduce regional inequalities in economic development?

After establishing the (Granger-) causality between transport infrastructure and economic development, we will provide the evidence of the growth effect of transport infrastructure and conduct a regional comparison. It should be noted that, even though transport investment cannot be regarded as the Granger cause of economic growth for underdeveloped provinces, a stable long-run equilibrium relationship between these two variables exists. This indicates that the improvement of transport infrastructure can still stimulate China's economic growth.

Through answering these sub-questions, some important findings emerge from our empirical study;

First of all, it becomes clear that our estimated output elasticity of transport infrastructure (0.13) in China is much lower than the results from other Chinese scholars (0.39 on average). This may be a result of using recent data from the period 1978-2008. In the latest decade, the state has spent a lot on the transport infrastructure construction, and the marginal returns are beginning to decline, although they are still positive and economically viable. Another part of the difference is due to the fact that both the national and local governments have reinforced the transport investments in the western region in the last few years, but large parts of the new western transport infrastructure are used less intensely. The utilization factor of the transport in the western provinces is relatively low due to the low density of the population. Therefore, transport infrastructure growth is bound to have a more limited impact on the economic growth and as a result the output elasticity will be accordingly smaller.

Secondly, the substantial transport investment has various economic returns according to the different development levels in China. The intermediately developed central provinces have the highest transport output elasticity, shortly followed by the wealthier coastal region, leaving the poorer western region with the lowest output elasticity. This implies that the transport infrastructure construction in the central provinces is most beneficial for the whole economy. More specifically, the elasticity of the backland region (including six provinces: Hunan, Hubei, Shanxi, Henan, Jiangxi and Anhui) is higher than the one of the full samples from the central provinces. This means these six provinces of the backland region represent the most crucial part of the development of the central region. This may reflect ''the emerging of the new economic center,'' a proposition advanced by Fujita et al. (1999), who argue that there is a strong possibility that regions between current economic centers and peripheral regions can become the new economic centers in the future. We can conjecture that the central region will probably play a dominant role in the operation of the whole system.

Moreover, the significant transport investment in recent years did little to reduce regional disparity in China because of its very limited elasticity of transport in the western region. The Chinese government invests heavily in the poorer western provinces hoping this may spur the economic development there. However, low efficiency in the utilization of the new transport facilities limits the economic revenue brought by the transport investment, as we detailed in chapter three. Thus, the regional allocation of transport infrastructure investment contributes little to reduce regional inequalities in economic development.

Do educational attainment and its distribution affect regional growth in China? Is this inequality in education at lower levels of economic development more impactful on economic growth than at higher levels of development? If so, what does this mean for China and its regions?

As the parallel of transport infrastructure, public investment in education is expected to have a similar economic performance with transport investment. Two important findings are summarized to address the sub-questions above.

Firstly, our empirical results show, as expected, the importance of the overall education of the population as a factor for sustained regional growth. The positive coefficient also confirms the relevance of great effort put into education development made by the Chinese government in recent decades. For an emerging country like China, the average educational attainment level matters to the nation's economic performance a great deal. Meanwhile, we find that the distribution of education also makes significant effect on China's growth. As for China in the present day, a strong negative long-run growth effect of inequality in educational attainment can be confirmed, implying the importance of the distribution of education resource at this moment and also in the near future.

Secondly, we evaluate separately the impact of education attainment (which is consistent with education infrastructure investment) and educational inequality in the lagging western region finding that the distribution of education resource in West China matters more for economic performance than education attainment itself. However, this pattern cannot be observed when we analyze national data. Consequently, we can say that inequality in education at lower levels of economic development is more impactful on economic growth than at higher levels of development. This finding is very important for China. Given the increasing public investment in education in those remote western provinces, those who receive education matter considerably more in the process of economic development. The broad access to education is more necessary for the economic growth of underdeveloped areas than only the strengthening of education itself.

Do falling transportation costs, due to substantial transport investments throughout Chinese cities, lead to a rising agglomeration of economic activities in core areas? What is the impact of public investment in education on the regional concentration of economic growth? Do transport investments and educational investments have a similar impact on regional economic growth patterns? How do they work out differently? And why?

We know that whilst public infrastructure may stimulate China's economic growth, it has no significant impact on reducing regional disparity in the post-reform decades by answering the research questions one through three. In question four, we will answer why the investment in public infrastructure did not narrow the regional gap.

Three new conclusions emerge after our empirical study.

The main empirical finding is that the transport infrastructure plays a key role in reshaping the spatial economic distribution in China, and an improvement of the transport facilities would accelerate the spatial concentration. Moreover, consistent with predictions of NEG models (Fujita et al., 1999; Ottaviano, 2008), the bell-shaped relation between transport improvement and geographic agglomeration can be verified for the case of China in our simulation, indicating that industries will spread to the peripheral areas if transport costs are lowered sufficiently, but this dispersion will take quite a long period of time due to China's development stage and unique social features. During this period, investment in transport infrastructure would allow more firms to further concentrate on the more developed Eastern China, which may widen the spatial inequity in China.

As the parallel of transport infrastructure, education in China does not have a clear distributive effect, indicating that the improvement of education attainment level does not lead firms to further concentrate in the core region or disperse. Given that the positive relationship between economic concentration and economic growth has been verified in some of the literature, there seems to be a trade-off between spatial equity (a more balanced spatial distribution of economic activities) and spatial efficiency (higher concentration and higher growth rate) induced by transport improvement. Nevertheless, the education infrastructure evades this trade-off because of its positive impact on local economic growth without any negative externalities. Consequently, for China, education should be more strongly emphasized than transport because its favorable policy results

Another important discovery of the study is that there seems to be a significant difference in distributive effect between transport infrastructure and education in the less developed western region.

The negative distributive impact of transport facilities in the poor regions found in our study indicates the outflow of industries induced by the increasing accessibility in the last decade. Conversely, the education attainment level in West China has a significant positive distributive effect, implying that the education investment there could facilitate the local agglomeration, which may stimulate economic growth there making it likely to catch up with the wealthier areas. From this view, improvement in education in the western provinces would definitely be a good option for the decision-makers aiming to achieve a spatial equity.

6.3 Policy recommendations of China's future infrastructure investment

Based on our findings summarized above, we provide several policy recommendations for the public infrastructure investment plan to Chinese governments as follows.

First of all, more than just transport infrastructure is needed to achieve effective economic growth in the less developed provinces. Current transport-stressed development strategy adopted by the central and western regions could not help them catch up with the coastal areas since our findings indicate that the transport investment that happened in the interior regions could not be the Granger explanation of local growth. As Zhang (2009) and Liu and Hu (2010) suggested, instead of a transport-stressed investment pattern, an integrated package of investment (for instance, other physical infrastructure, including electricity, gas, water, environment control, sewage facilities, urban public facilities, and social infrastructures, such as education, social security, science technology, and medical treatment) is urgently needed for current China. Meanwhile, our results reveal that the current infrastructure investment policies in the central and western regions are not effective, which is possibly due to transport infrastructure created by governments in the absence of strong demand pressures, will have little or no impact on economic growth. Chinese governments should consider investment in transport infrastructure in the future investment planning in conjunction with complementary efforts to overcome other barriers to regional economic growth.

Secondly, transport investment in central provinces could be given priority. In the latest decade, the 'collapse' of central region aggravated the East-West gap. The unique location of the central region emphasized the importance of transport infrastructure construction there. As the argument of 'the emerging of new economic center' we proposed in Chapter 4, we believe that the new transport facilities could help the central region speed up the pace in becoming the new economic center. The central government should reconsider the current transport infrastructure investment distribution among macro-regions. The new investment strategy could focus on Wuhan, Zhengzhou, and other central transportation hub cities. By improving the accessibility of the central market, the central provinces have the ability to undertake the industrial transfer of the eastern provinces, and further shift the industry to generate better conditions in the western provinces, which could definitely promote their economic development.

Thirdly, for the purpose of growth, the Chinese government would benefit from emphasizing a more balanced distribution of education attainment. For China at this moment, the negative effect of inequality in educational attainment is very strong. An equal distribution of education is desirable for educational development and also consistent with the target of economic growth. China would perform better if it allocated its educational resources more evenly (the universal primary and near-universal secondary education is preferable), given the limited resources devoted to education. Meanwhile, the Chinese government should consider the stage of development of a region when relevant policies to foster economic growth through education are made. For the western areas that lag behind, equity of education is more important than average education level. Thus, the Chinese government should heed the question of how it spreads its investment resources in education over its population in the lagging regions, if it wishes to optimize its education policy.

Last but not least, regarding the role of public infrastructure in reducing regional inequality, investment in education infrastructure is highly recommended, since education improvement can stimulate China's economic growth with a more even pattern of development across regions. However, the policy result of investment in transport infrastructure seems to face a trade-off between spatial equity (more even spatial distribution of economic activities) and spatial growth (higher concentration and higher growth rate). Especially for the lagging western areas, education development would benefit from being strengthened instead of transport infrastructure. The economic return of new transport investment in these remote western areas has been very limited in previous years because of diminishing marginal effect (transport in West China has been raised to a new level by the outpour of public investment). The fact is that, in those western provinces, especially in Tibet, Xinjiang, and Gansu, there is very little demand for traffic, therefore building another road or new airport will unlikely be of much benefit. By contrast, the results of our research imply that it is important to put more education investment in the less-developed provinces, both for reasons of economic efficiency and spatial equity.

6.4 Research limitations and reflections

This research project aims to address the role of public infrastructure in stimulating growth and reducing regional disparity in China. Thus, we demonstrate a causal relationship between transport infrastructure and economic growth, evaluate the growth effect of transport infrastructure and education by two separate regional comparative analyses, and investigate the impact of public infrastructure (both transport infrastructure and education) on economic agglomeration. While the research sheds new light on the impact of public infrastructure on China's economic development, it has several limitations.

(1) The main limitation of our econometric methods is the use of Granger causality to examine the causality between transport infrastructure and regional economic growth in Chapter 2. Indeed, Granger causality is not a real cause relationship. This causality is somewhat of a prediction, which is significant from a statistical point of view. However, the results of Granger causality still have great value in our empirical studies. First of all, the Granger causality test panel adopted in our study could identify the long-term equilibrium relationship between transport investment and economic growth, which could confirm the generative effect of transport investment during the post-reform period. Secondly, our findings indicate that the amount of transport investment at any point is not a reliable predictor of the level of economic growth at a later point in time in the underdeveloped regions, thus ample investments in transport infrastructure do not bring the benefits people expect in these areas. As a result, the transport-stressed development strategy in the interiors has limited impact on catching up with the coastal region. Evidently, it is an important finding and useful for Chinese authorities to modify their public infrastructure investment patterns.

(2) Another limitation lies in the data we adopt in the empirical study. Our empirical studies examine the growth effect of transport infrastructure stock (in Chapter 3) or a certain type of transport infrastructure (highways in Chapter 5), which can only offer macro investment policy suggestions taking transport infrastructure as a whole. In fact, we believe the economic benefits of transport infrastructure could vary substantially according to different modes, largely due to differences in each transport facility's market size and production cost asymmetries. Meanwhile, different quality levels of

transport infrastructure also matter for economic performance, since the magnitude of impact on travel time and thus manufacturing cost savings from highways investment in different categories (classified by technical standards) is different. Such differences, either in modes or qualities, therefore, present a good opportunity for future research which examines the economic effects of transport infrastructure, dividing transport facilities into various modes or developing a comprehensive index to measure both quantitative and qualitative characteristics of each mode of transport infrastructure. The results from those studies could provide more specific policy suggestions on the distribution of public infrastructure investment among types of transport facilities and among categories of certain transport infrastructure, for instance, the highways.

Similar to transport infrastructure, we give limited attention on the growth effect difference among various educational levels (in Chapter 3 and Chapter 5). Obviously, the discrepancies in the levels of education attainment will also give rise to differential growth effects. As we discussed in Chapter 5, the universal primary and near-universal secondary education may have a higher growth return for current China. The contribution rate of tertiary education in China appeared to be very limited at 2.04%, but the contrition rate of education on average (including primary, secondary and tertiary education) reached 5.69% in 2010 (Li and Cha, 2006; Wang, 2013), suggesting the importance of basic education for China's current stage of development. Therefore, it seems to be necessary to uncover new research on evaluating the economic contributions of different education levels in Chinese regions in future studies.

(3) This research project makes a great effort in answering how public infrastructure impacts the local economy, but cannot provide the exact improved scheme for China's public investment allocation in the future. Our empirical findings indicate that investment in transport infrastructure (and education) is a productive stimulus contributing to China's economic growth, which is in line with the

expectations of decision-makers (Chapter 3). However, transport infrastructure and education have different roles in balancing China's economy - transport investment has not contributed to spatial equity while education did (Chapter 5). We believe these findings are robust enough to serve as the basis for policy making in real life due to the convincing evidence provided in Chapter 5. Our previous paper (Yu et al., 2013) also confirmed the existence of the negative spillover effect of transport investment in the western region using the macro-level data. When all other things are equal, an improvement in the road network could accelerate the spatial agglomeration of economic activities in the core region, which could widen the regional gap. By contrast, improving the education attainment level can enhance growth, disperse industrial distribution and lower disparity. This result has significant policy implications for China, where the majority of government subsidies to poor inland regions are used to construct transport infrastructure. Based on our findings, we propose that China should increase investment in education and reduce its transport investment in the underdevelopment provinces to some extent with the purpose of equality. However, we cannot provide the appropriated investment data of transport infrastructure (and education) for Chinese government based on current research findings. Thus, in the future research, we aim to provide a package of policy choices using scenario technology, changing the amount of investment according to the Chinese government's preference (since there is a trade-off between spatial growth and spatial equality). Based upon these findings, we can answer how much public investment should be put in transport facilities (and in education) in order to gain a higher and more balanced growth effort, and also better realize the economic benefits brought by this public infrastructure investment.

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Appendixes

A Appendix to Chapter 2: Methodology of Granger Causality Test for Panel Data

The methodology follows the time series causality analysis procedures discussed in the literature (Engle and Granger, 1987; Granger, 1988). For panel data, several studies have focused on examining Granger causality between variables (Kao, 1999; Pedroni, 2004; Banerjeeand Carrion-i-Silvestre, 2006). The Granger representation theory states that if two series are cointegrated, their long-run equilibrium should be represented by the ECM (Engle and Granger, 1987). ECM combines short-term fluctuations and long-term balance together. To construct an ECM, we need to address three issues: stationarity, cointegration and model construction. Thus, our econometric methodology proceeds in three stages. First, we perform the panel unit root test to ascertain the order of integration of the variables. Second, conditional on finding that all variables are integrated of order 1, we test for panel cointegration using the approach suggested by Engle and Granger (1987). Third, we test for Granger causality between real GDP and transport investment in a panel data context. The details of the three methods are outlined below.

A.1 Panel Unit Root Test.

The first step is to determine whether the time series are stationary, which is a necessary condition for the time series analysis. Consider the following autoregressive specification:

$$y_{it} = \rho_i y_{it-1} + \varepsilon_{it}$$

Where $i = 1, \ldots, N$ for each province in the panel; $t = 1, \ldots, T$ refers to the time period; ρ_i are the autoregressive coefficients and ε_{it} are the stationary error terms. If $\rho_i < 1$, y_{it} is considered weakly trend stationary, whereas if $\rho_i = 1$, then y_{it} contains a unit root. Levin et al.'s (2002) panel unit root tests assume a homogeneous autoregressive unit root under the alternative hypothesis. Maddala and

Wu (1999) and Choi (2001) suggest comparable unit root tests to be performed using the non-parametric Fisher statistic. Carrion-i-Silvestre et al.'s (2005) panel unit root tests examine the null hypothesis of stationarity. In our study, we adopt four different tests: LLC test, IPS test, ADF-Fisher test and PP-Fisher test.

A.2 Cointegration Test.

Cointegration theory provides the theoretical foundation to find long-run equilibrium relationships among two or more non-stationary variables and to construct an ECM for cointegrated variables. Cointegration relationship among the variables is long term and stable. This relationship can explain how the change of a variable will affect the change of other variables. We test for panel cointegration using Engle and Granger's (1987) two-step test. A panel function regression is undertaken by estimating the long-run model specified in Equations (A2) and (A3) in order to obtain the estimated residuals:

$$\ln GDP_{it} = \alpha_{0i} + \alpha_{1i} \ln TR_{it} + \varepsilon_{it}$$

$$\ln TR_{it} = \beta_{0i} + \beta_{1i} \ln GDP_{it} + \varepsilon_{it}$$

Here, all variables are as defined as in the paper. Then, we use panel unit root tests to identify whether these residual series are stationary. If the residual series can reject the null hypothesis of no cointegration, there exists a long-run equilibrium relationship between variables.

A.3 Granger Causality Tests Based on ECM.

It is important to note that the expression '*x* Granger causes *y*' does not mean *y* is an effect or result of *x*. Granger causality measures time precedence, but does not itself indicate causality in the usual sense of the expression. Economic arguments are essential to accepting what is commonly meant by causality. Given that the variables are cointegrated, a dynamic ECM is estimated to perform Granger causality tests in order to identify the direction of the long-run causality and to examine its causal relationship in the short term:

$$\Delta \ln GDP_{it} = \alpha_{1i} + \sum_{k=1}^{m} \beta_{1ik} \Delta \ln GDP_{it-k} + \sum_{k=1}^{m} \gamma_{1ik} \Delta \ln TR_{it-k} + \lambda_{1i} ECM_{it-1} + \varepsilon_{1it}$$

$$\Delta \ln \mathrm{TR}_{it} = \alpha_{2i} + \sum_{k=1}^{m} \beta_{2ik} \Delta \ln GDP_{it-k} + \sum_{k=1}^{m} \gamma_{2ik} \Delta \ln TR_{it-k} + \lambda_{2i} ECM_{it-1} + \varepsilon_{2it}$$

Here, *m* is the lag length set at 3 based on likelihood ratio tests, Δ denotes the first difference of the variable and ECM_{it-1} denotes the error correction term. In the real GDP, Equation (A4), short-run causality from transport investment to real GDP is tested, based on $H_0 : \gamma_{1ik} = 0 \forall_{ik}$. In the transport investment, Equation (A5), short-run causality from real GDP to transport investment is tested based on $H_0 : \beta_{2ik} = 0 \forall_{ik}$. For long-run causality, the null hypothesis of no long-run causality in Equations (A4) and (A5) is tested by examining the significance of the t-statistic for the coefficient on the respective error correction term represented by λ .

B Appendix to chapter 2: Data selection

The data used in this estimation is organized as follows:

(1) Price deflators: data on GDP and public investment are converted to constant prices of 1996.

(2) Labor input: annual data on the employment were obtained for each province. These data are compiled from China statistical yearbook, province statistical yearbook. We use the year-end data since the average data of a year is unavailable from currently existing materials.

(3) Capital input

Data of capital input is from "capital construction investment data grouped by various industries" of China Statistical Yearbook from various years. However, the result by this data will underestimate the capital investment. But since there is a direct ratio between capital construction investment and total investment of each industry, it should be a nice substitute.

Private sector capital: "Agriculture, forestry, animal husbandry and fishing", "extractive industry", "Manufacturing", "Wholesale and Retail Trades", "Catering industry", "Finance and insurance", "the real estate", "other industries" in China Statistical Yearbook.

Transport infrastructure investment: "the capital construction investment of transport infrastructure" in China Statistical Yearbook.

Other infrastructure investment: "the capital construction investment of electricity, gas, water supply", "the capital investment of sanitation, environment and public accommodation management" in China Statistical Yearbook.

C Appendix to chapter 2: Calculation method for transport capital stock

In this study, we adopt a widely known method to calculate capital stock, 'perpetual inventory method', pioneered by Goldsmith (1951). The stock of transport capital is constructed by first estimating the stock for each county in a base year, then depreciating that stock while adding the value of new expenditures in each successive year. This is done according to the relationship shown below.

$$TR_{i,t} = (1-\delta)T_{i,t-1} + I_{i,t}$$

Where

TR = transport infrastructure stock

I = investment in transport infrastructure

δ = a depreciation rate

'I' indexes provinces, 't' indexes years

In this paper, we assume the depreciation rate of the transport infrastructure capital is 9.6%, as specified by Zhang et al. (2004). Following Young (2003) and Shan (2008), we initiate the capital stock in 1999 by assuming that the real investment growth recorded in the first five years of the data extends into the infinite past. Specifically, the capital stock in 1978 is given by real investment in 1978 divided by the depreciation rate plus the average annual growth of real investment between 1978 and 1983. Similar formulas are used to calculate private sector capital stock and public sector capital stock.