# THE REGIONAL MACROECONOMIC EFFECTS OF PUBLIC INFRASTRUCTURE IN CHINA
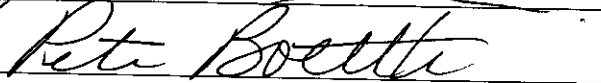
by

Chunpu Song
A Dissertation
Submitted to the
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George Mason University
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The Requirements for the Degree
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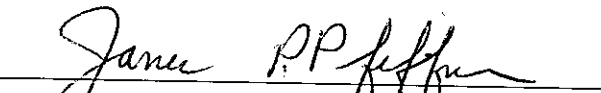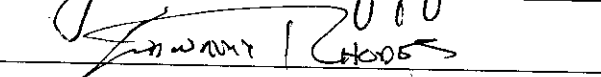Doctor of Philosophy
Public Policy

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# Dedication

This is dedicated to my parents.

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Finally, special thanks go to my parents, whose loves and supports enabled me to complete the dissertation and also inspired me to move forward persistently.

# Table of Contents

# List of Tables

# List of Figures

# List of Abbreviations and Symbols

| | |
|---|---|
| ADF | Augmented Dickey Fuller test |
| CAAC | Civil Aviation Administration of China |
| CADF | Cross-Sectionally Augmented Dickey Fuller test |
| DOLS | Dynamic Ordinary Least Squares |
| DPA | Directly Productive Activities |
| FDI | Foreign Direct Investment |
| FMOLS | Fully Modified Ordinary Least Squares |
| GDP | Gross Domestic Product |
| GLS | Generalized Least Squares |
| GNI | Gross National Income |
| HC | Homogeneous Causality |
| HENC | Heterogeneous Non Causality |
| HNC | Homogeneous Non Causality |
| LBI | Locally Best Invariant |
| IMF | International Monetary Fund |
| LM | Lagrange Multiplier |
| MA | Moving Average |
| MPT | Ministry of Posts and Telecommunications |
| NSB | National Statistical Bureau (China) |

| | |
|---|---|
| OECD | Organization of Economic Cooperation and Development |
| OLS | Ordinary Least Squares |
| PANIC | Panel Analysis of Nonstationarity in Idiosyncratic and Common components |
| PPP | Purchase Power Parity |
| PRC | People's Republic of China |
| PSEGW | Production and Supply of Electricity, Gas and Water |
| PTE | Posts and Telecommunications Enterprise |
| R&D | Research and Development |
| TFP | Total Factor Productivity |
| TSPT | Transport, Storage, Post and Telecommunication Services |
| SOC | Social Overhead Capital |
| U.S. | The United States |
| VAR | Vector Autoregressive |
| WDI | World Development Indicator |

# Abstract

THE REGIONAL MACROECONOMIC EFFECTS OF PUBLIC INFRASTRUCTURE IN CHINA

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This dissertation examines the relationship between public infrastructure and regional economic productivity in China. Based on a panel data set for 29 regions of China for a 17-year period of 1987-2003, a three-step nonstationary panel analytical procedure is conducted to investigate whether public infrastructure is productive in China. The results show that public infrastructure is productive in China across 29 regions from 1987 to 2003, with a moderate estimated output elasticity of 0.15. Among the eastern, central and western mega-regions in China, the productivity effect of public infrastructure is largest in the central mega-region and smallest in the eastern mega-region. Moreover, the estimated output elasticity in regard to the first-order neighboring public capital is about 0.11, which is even larger than that regarding public capital (0.09). Finally, a panel Granger causality test is conducted to investigate the nature of the possible causal

relationship between public infrastructure and economic output in China. The results demonstrate that there exist strong bilateral causal relationships between public infrastructure and economic output in China. In particular, public infrastructure may influence economic output during a longer time horizon than economic output does for public infrastructure in China.

# 1 Introduction

This dissertation presents an empirical analysis of the regional macroeconomic effects of public infrastructure in China based on panel datasets of 29 Chinese regions for the 17-year period of 1987-2003. The objectives of the research are to analyze the regional productive effects of public infrastructure in China using the techniques for nonstationary panel data models and also investigate a possible causal relationship between public infrastructure and productivity in China using a panel Granger causality test.

## 1.1 Background

For a long time, the economic effects of public capital and infrastructure received little attention in economic growth and development theories although such public infrastructure as roads, ports, piped water supply and others have always been considered as the prerequisite condition for social and economic developments. The official definition of public capital is provided by IMF (2001) in its Government Finance Statistics Manual, which distinguishes three types of public capital: infrastructure capital, general purpose assets and heritage assets. It should be noted that public capital consists of infrastructure assets in most empirical studies. Meanwhile, according to the World Development Report 1994 (World Bank, 1994), economic infrastructure includes services

from public utilities, public works and other transport sectors[1]. In this research, the terms of public capital and public infrastructure are equivalent and interchangeable, both of which refer to the economic infrastructure coincided with the definition of the Word Bank (1994). Moreover, infrastructure has two important characteristics: (i) the fixed cost of providing infrastructure assets is substantial due to indivisibilities, (ii) the marginal cost of adding an extra user is low (Kamps, 2004), which makes infrastructure assets exhibit some feature of public goods.

In the 1950s, the concept of public infrastructure is introduced to the field of economics by such development economists as Paul Rosenstein-Rodan, Ragnar Nurkse, and Albert Hirschman, who assigned the infrastructure a significant role for economic growth in those undeveloped countries (Hirschman, 1958). Rostow (1956), who proposed the five stages theory of growth, argued that investments in public infrastructure are indispensable to those countries experiencing the economic development transition from the preconditions for take-off stage to the take-off stage.

With the emergence and popularity of the neoclassical economic growth models and theories, public capital (total capital employed in the public sector) was separately considered and theoretically integrated into the neoclassical growth theory by Arrow and Kurz (1970), who extended the aggregate production function to include the stock of public capital as another input apart from labor and private capital. Before that, neither the popular neoclassical growth models of Solow model nor Ramsey-Cass-Koopmans

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[1]The detailed definitions of public capital and infrastructure will be reviewed in the chapter of literature review.

model separately considered the economic effects of public capital, which was instead considered to be included in the "technological changes". Arrow and Kurz (1970) then further related the determination of the optimal resource allocation between private and public sectors to the goal of getting and keeping the whole economy functioning on an optimal growth path.

Although public capital was officially integrated into neoclassical growth theory by Arrow and Kurz in as early as 1970, little empirical research has been conducted to study the actual economic effects of public capital since then. The beginning of a large body of empirical literatures on the economic effects (especially the productive effects) of public capital is generally related to the influential work of Aschauer (1989), who estimated the elasticity of output with respect to public capital in the United States from an aggregate production function in log-linear form with labor, private capital and public capital as inputs. Aschauer (1989) obtained an estimate of 0.39 for the elasticity of output regarding public capital in the United States, which prompted him to conclude that public capital was highly productive in the United States.

The argument of Aschauer (1989) was enlightened and significant in that it spurred a number of studies examining the productive effects of public capital in the United States as well as in other parts of the world based on the aggregate production function approach. Comprehensive reviews of this literature can be found in Munnell (1992), Gramlich (1994), Seitz (1995), Pfaehler et al. (1996), Sturm (1998), Buttom (1998), and Nijkamp and Poot (2003). However, the main finding of these reviews is that the point

estimate of the elasticity of output regarding public capital differs greatly across studies (ranging from -0.11 to 0.73), which makes many researchers question the usefulness of the production function approach with a great critique. Specifically, the production function approach is not critiqued for the method itself, but for such econometric problems: reverse causation, and non-stationarity (spurious correlation).

Reverse causation refers to the fact that the regression elasticity results on public capital can also be interpreted to mean that it is economic growth that really causes more public capital spending but not the way expected. Non-stationarity of the data refers to the fact that the corresponding time series data for the dependent variable and regressors in the studies of the relationship between public capital and private output may be non-stationary, which can result in unreliable and spurious estimations of the results of statistical tests and inferences. As to the problem of reverse causation, the popular "Granger causality test[2] " has been generally used to investigate whether there are causal linkages between productivity and public capital from both sides. By contrast, the problem of non-stationarity (spurious correlation) is just the one that is put forward by many researchers as the most serious econometric problem to the aggregate production function approach. Although it has been generally accepted that most of the macro time series variables for output, public capital and others in the empirical studies of estimating the output elasticity of public capital are not stationary and the related statistical results

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[2]The "Granger causality test" intends to investigate whether changes in one of two variables have statistically significant relationships with past changes in the other. Details on this test can be found in Granger (1969).

are therefore subject to be spuriousness, it takes some time before a consensus can be reached on how to resolve the non-stationarity problem.

Supported by many researchers (Aaron, 1990; Hulten and Schwab, 1991; Jorgenson, 1991; Tatom, 1991, 1993; Sturm and Haan, 1994), the method of first-differencing equations had been believed to be able to transform non-stationary time series to stationary ones and to remove the common trends for the estimation of true relationships between the two variables of output and public capital. Hulten and Schwab (1991), Totam (1991) and Sturm and Haan (1994) estimated the parameters of the aggregate Cobb-Douglas production function time-series econometric model in a first-difference specification, all of which find that the positive coefficient on public capital is much smaller than that in the estimation based on the level of the public capital and is no longer statistically significant.

However, Munnell (1992) questioned the validity of the first-differencing method, arguing that differencing could destroy any long-term relationships in the time series and could yield implausible estimations of the coefficients for public capital, labor and other independent variables which are exactly the cases in the studies of Hulten and Schwab (1991), Totam (1991) and Sturm and Haan (1994). Accordingly, Munnell (1992) argues that the variables should be tested for co-integration[3] and then adjusted before estimating the relationship. In recent years, more and more researchers have realized that not only the extent to which the time series variables are non-stationary, but also whether they

[3]If variables are tested to have a unit root, then these variables are not co-integrated.

grow together over time and converge to a certain long-run relationship (co-integration[4])

should be examined simultaneously.

There are many unit root tests that can be used to test for co-integration (see, e.g., the

survey made by Dolado et al. 2001), among which the augmented Dickey-Fuller test and

the Engle-Granger test are the most widely used. It should be noted that if the variables

have been tested for co-integration and found not to be co-integrated, then the variables

must be differenced to become stationary. Based on the similar econometric equation as

that used by Aschauer (1989) and Munnell (1990), Sturm and Haan (1994) use the

augmented Dickey-Fuller test to test the co-integrations of these non-stationary time

series variables with the main finding that the hypothesis that all the level of time series

variables (output, labor, public capital, capacity utilization rate and trend) are integrated

must be rejected. Kamps (2004) also got the finding of no co-integration when applying

the Engle-Granger test when testing for co-integration in his estimates of public

productivity for 22 OECD countries separately. Do the above two non co-integration

findings mean that differencing the variables is the only method for inducing stationarity?

The answer is surely "no".

It is generally known that "unit root tests and tests for co-integration have low power to

discriminate between unit root and near unit root processes" (see, e.g., Enders, 1995: 251-

254), which is particularly severe for small samples (Campbell and Perron, 1991). Since

the sample periods for most empirical studies on the productive effects of public capital

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[4]Co-integration between two variables also means that "there must exist an error correction mechanism, with at least one of the two variables adjusting to keep the long-run equilibrium relationship intact" (Canning and Pedroni, 1999: 3).

are only several decades, many researchers believe that "one way to increase the power of unit root tests and tests for co-integration is to make use of the cross-section dimension of the data in addition to the time-series dimension" (Kamps, 2004: 45). Over the past several years, significant body of literature coupled with corresponding methods has emerged to analyze non-stationary panel models[5], while the econometric methods for non-stationary panel models rarely been used in the analysis of the productive effects of public capital, especially in the estimation of the elasticity of output in regard to public capital[6].

In recent years, another popular view states that the productive effects of public capital should be lowest in very poor and very rich countries, but should be highest in middle-income countries or countries experiencing rapid growth. Therefore, a series of empirical studies on the productive effects of public capital in different countries experiencing different periods of economic growth and development should be conducted comprehensively before a reliable conclusion can be made on the productive effects of public capital. Unfortunately, most of the existing empirical literature examines the productive effects of public capital for developed and very rich countries such as the United States, Japan and Germany, while few studies have been conducted for poor and/or developing countries while experiencing rapid growth.

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[5]The comprehensive treatment of methods for panel data models can be found in Baltagi (2005) and Hsiao (2003).

[6]The econometric methods for non-stationary panel models have been extensively used to test purchasing power parity (Pedroni, 2001) and growth convergence (Lee et al., 1997).

In response to the two major deficiencies in the current literature on the productive effects of public capital, the dissertation is designed to apply these newly-developed methods for non-stationary panel data models to analyze the productive effects of public capital in China. Since its market-oriented economic reform and opening up in 1978, China has been among the countries experiencing the fastest economic growth and development in the world. During the past few years, a growing body of literature has focused on China's economic growth and development, while the question of productive effects of public capital or infrastructure in China is rarely raised and studied. Actually, the states of China and the transition of Chinese government spending policies in the past twenty years provide an excellent and unique opportunity to empirically study the productive effects of public capital or infrastructure in China, which should surely become an important and indispensable complement to the current literature on this issue. Although there have existed some empirical studies attempting to analyze the productive effects of public capital in China (Wang, 2006; Fan et al., 2004; Zhu, 2004; Lou, 2003; Ma, 2000), these studies are fairly limited and far from satisfying, especially leaving such econometric problems as reverse causation and non-stationarity (spurious correlation) as discussed unresolved.

In addition to analyzing the productive effects of public capital in China, the dissertation also attempts to study the causality relationship between economic output and public capital in China. It has been generally accepted that the Granger test is one of the most popular and useful methods for accessing the nature of the causal relationship between two variables. Generally speaking, variable x is Granger causing variable y if y can be

better predicted by using all available information than by using the information except from x. Although originally designed for time series pairs, Granger tests have been modified by some researchers to evaluate causal relationships in panel data (Holtz-Eakin, Newey, and Rosen, 1988; Arellano and Bond, 1991; Hurlin and Venet, 2001; Hurlin, 2004). The panel Granger causality test is superior to the traditional Granger causality test on time series pairs in that the former can produce more meaningful results with shorter time periods and generates more efficient results than the latter by incorporating many more observations. However, although the traditional Granger causality test has been used to investigate the causal relationship between output and public capital using the time-series data, no panel Granger causality test has been employed to study the causal relationship between output and public capital, let alone in the context of China. Therefore, this dissertation will adopt the panel Granger causality test recently developed by Hurlin (2004) to study the causal relationship between economic output and public capital in the context of China.

## 1.2 Questions and Hypotheses

The research aims at applying the newly-developed methods for non-stationary panel data models to assess the productive effects of public capital in China based on an aggregate production function approach and also to conduct a panel Granger causality test to investigate the causal relationship between economic output and public capital in China. The research proposed will address two research questions:

**Research Question 1:** Is the public infrastructure capital productive across Chinese regions over the 1987-2003 period?

**Research Question 2:** Is there a robust causal relationship from public capital to economic output or vice versa in China over the 1987-2003 period?

Answers to the above questions are critically important in examining and understanding the regional macroeconomic effects of public infrastructure in China. Building on the extensive literature on the productive effects of public capital and the causal relationship between public capital and economic output, the detailed hypotheses of this research can be specified as follows:

**Hypothesis 1:** Public capital is productive across Chinese regions over the 1987-2003 period. That is, the estimated elasticity of output with respect to public capital based on the panel-data aggregate production function model is positive and statistically significant.

**Hypothesis 2:** There is a robust causal relationship from public capital to economic output in China over the 1987-2003 period.

## 1.3 Policy Implications

In the past two decades, China has experienced great economic growth and development along with huge spending in public infrastructure and a rapid increase in public capital stock. In this situation, it is extremely important and necessary for policy makers and researchers in China as well as in the world to evaluate the productive effects of public

capital in China and especially the extent to which the productive effects might be. Furthermore, the question on whether public capital stock causes economic output or economic output causes public capital stock has always been a heated topic among both economists and policy practitioners. Specifically, the policy implications of the dissertation are specified as follows.

For one thing, whether the public capital in China has a positive effect on productivity and the extent to which extent the productive effects are have important policy implications in China as well as for other developing countries. If the productive effect of public capital in China is confirmed in light of the use of convincing econometric techniques, policy makers at different levels in China may consider improving current policies and formulating new policies to promote financial spending and investments in public infrastructure and thus increase the stock of public capital rapidly. Similarly, the successful experience in China may also be invaluable to those developing countries attempting to achieve rapid economic productivity and growth. Moreover, even if the productive effects of public capital in China may not be supported in the dissertation, the research may still provide valuable policy suggestions for policy makers and practitioners in both China and other countries.

For another reason, ascertaining the nature of the causal relationship between public capital stock and economic output also has important policy implications in China. If the hypothesis that public capital stock does cause economic output in China is verified, the research will provide a direct theoretical basis and support to those policies aiming to

stimulate economic output by increasing public investments and thus public capital stock in China. Even if the hypothesis that public capital stock does cause economic output in China cannot be supported, the research could still suggest that policy makers be cautious when selecting increase of public capital stock as an alternative policy to stimulate economic output in china.

## 1.4 Contributions

There are several major attributes that makes this research differerent from previous studies.

First, the study period is extended to range from 1987 to 2003 and for the first time the data for public capital across Chinese regions is fully estimated and calculated. Second, for the first time the newly-developed techniques for non-stationary panel data models are employed to evaluate the productive effects of public capital in China under the framework of an extended aggregate production function model. Third, the panel Granger causality test is used to study the nature of the causal relationship between economic output and public capital stock in China for the first time.

## 1.5 Organization of Dissertation

The rest of the dissertation consists of six chapters. Chapter 2 provides the exact definition of infrastructure used in the research. Meanwhile, the main characteristics of infrastructure are also briefly discussed. Moreover, three important economic growth theories that are highly related to infrastructure are addressed in detail.

Chapter 3 provides both an overview of infrastructure development in China and a structural analysis of infrastructure investment in China. Moreover, the chapter compares China's infrastructure development with those of other countries in the world. Finally, some important institutional and policy factors behind the rapid growth of public infrastructure in China are also reviewed and discussed.

Chapter 4 reviews the literature on the relationship between infrastructure and economic productivity. First, the theoretical relationship between infrastructure and productivity is examined. Second, those empirical studies that employ the production function approach to investigate the productive effects of public infrastructure based on both time series data and panel data are critically reviewed. Finally, those empirical studies on the economic effects of infrastructure in the context of China are also reviewed and assessed.

Chapter 5 discusses a three-step nonstationary panel analytical procedure to investigate the productive and spillover effects of public infrastructure and also a panel Granger causality test to study the relationship between infrastructure and productivity. Variable measurement and data sources employed in the research are also addressed.

Chapter 6 presents empirical results of the nonstationary panel analytical procedure for investigating the productive and spillover effects of public infrastructure in China. Empirical results for the panel Granger causality test of the possible causal relationship between infrastructure and productivity in China are also estimated and discussed.

Chapter 7 presents the conclusions and policy implications of the research. The chapter is mainly in response to the research questions proposed in the introduction. However, directions for future research are also presented.

# 2 Infrastructure and Economic Growth Theories

This chapter briefly reviews some important issues on infrastructure and related economic growth theories. In the first part, the definition of infrastructure is reviewed to develop the definition employed in the dissertation. The second part discusses some important characteristics of infrastructure. The third reviews important economic growth theories related to infrastructure are presented. The final part concludes.

## 2.1 Definition of Infrastructure

Interest in infrastructure originated from the 1950s, when development economists such as Paul Rosenstein-Rodan, Ragnar Nurkse, and Albert O. Hirschman considered infrastructure as an inclusive term of many activities and services referred to as Social Overhead Capital (SOC). Rosenstein-Rodan (1943) first put forward the concept of social overhead capital to highlight his view that a society must have sufficient capital accumulation before general industrial investments can be made. Social overhead capital, which especially included such basic industries as public utilities, transportation and telecommunications, played a significant role in the process of industrialization.

Hirschman (1958) made a clear distinction between Social Overhead Capital (SOC) and Directly Productive Activities (DPA). In his view, SOC is generally defined as

"comprising those basic services without which primary, secondary, and tertiary productive activities cannot function" (Hirschman, 1958: 83). Therefore, the definition of SOC may include all public services from law and order, education and public health to transportation, communications, power, water supply, and irrigation and drainage systems. According to Hirschman (1958), the hard core of the definition of SOC can be restricted to transportation and power.

Mrinal Datta-Chaudhuri (1980) discussed his understanding to infrastructure when critically evaluating Rosenstein-Rodan's development strategy of the "big push" toward "balanced growth". In his opinion, which sectors might constitute infrastructure are difficult to identify. Accordingly, he attempted to differentiate the two concepts between a narrow definition of infrastructure and Social Overhead Capital. Specifically, a narrow definition of infrastructure, which focuses on the "hard" public utilities, may include transportation, communication, power utilities, urban facilities and even irrigation systems and other related construction works, e.g., dams. In terms of social overhead capital, which was first introduced by Rosenstein-Rodan (1943) in the context of a developing economy, it should correspond to a wide definition of infrastructure, which included not only the narrow definition of infrastructure, but also such "soft" public utilities as "education, scientific research, sanitation and public health, and the entire structure of the judicial -administrative system" (Mrinal Datta-Chaudhuri, 1980: 239).

According to the World Development Report 1994 (World Bank, 1994), economic infrastructure includes services from "(i) public utilities (e.g., power,

telecommunications, piped water supply, sanitation and sewerage, solid waste collection and disposal, and piped gas), (ii) public works (e.g., roads and major dam and canal works for irrigation and drainage), (iii) other transport sectors (e.g., urban and interurban railways, urban transport, ports and waterways, and airports)". It is clear that the definition of infrastructure established by World Bank (1994) coincides with the narrow definition of infrastructure defined by Mrinal Datta-Chaudhuri (1980).

From the above review, it is reasonable to conclude that infrastructure can be understood from both the narrow and wide conceptual frames. Specifically, the narrow definition includes the narrow definition of infrastructure by Mrinal Datta-Chaudhuri (1980) and the general definition by the World Bank (1994), while the wide definition corresponds to Social Overhead Capital (Rosenstein-Rodan, 1943; Hirschman, 1958), which includes the narrow definition of infrastructure as well as the "soft" public utilities. In this dissertation, the definition of infrastructure is a narrow one in nature and strictly corresponds to the one defined by World Bank (1994). Moreover, as a research to study the regional macroeconomic effects of infrastructure in China, the dissertation is designed to emphasize the characteristics of infrastructure as a kind of capital. Therefore, infrastructure is regarded as a kind of public capital[7] to such an extent that the two terms of infrastructure and public capital are the same in nature and completely interchangeable in the dissertation.

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[7]The IMF (2001, p.112) distinguishes three kinds of public capital: "(i) infrastructure capital (e.g., streets, highways, lighting systems, bridges, communication networks, canals, and dikes), (ii) general-purpose assets (e.g., schools, road-building equipment, fire engines, office buildings, furniture, and computers), and (iii) heritage assets (e.g., museums)". The term "public capital" in the research refers to "infrastructure capital" indeed.

## 2.2 Characteristics of Infrastructure

As a kind of public capital (infrastructure assets), the main characteristics of infrastructure, which are highly related to those of public goods, can be specified as follows.

- **Low mobility**: the feature refers to the fact that most infrastructure elements are fixed to particular geographical locations and spatially fixed in nature.

- **Substantial initial investments**: most infrastructure establishments require substantial initial investments to reach minimum workable scales mainly due to the invisibilities of infrastructure, which means that a whole infrastructure establishment cannot work properly unless the different and highly-related parts of the system are all finished.

- **Low marginal cost of adding an extra user**: within a certain scope, adding an extra user to an existing infrastructure element does not increase extra cost to the infrastructure.

- **External economy**: services from infrastructure elements also provide benefits to the surrounding business and households of a region.

- **Natural monopoly**: for most infrastructure elements characterized by very large investments, it is often inefficient to have more than a single provider of the

services from an infrastructure asset in a region mainly due to economies to scale[8].

- **Public and private ownership coexistence**: Because of the features of natural monopoly and public goods, some infrastructure assets (local utilities, lighthouses and dikes) are provided by the public sector in order to price them efficiently. In contrast, some other assets (telecommunications), which may be subject to low potential market failure (World Bank, 1994), can and should be provided by the private sector under specific regulations in many cases.

In a word, the general characteristics of infrastructure may include such aspects as low mobility, substantial initial investments, low marginal cost of adding an extra user, external economy, natural monopoly and public and private ownership coexistence. A good understanding of these characteristics is almost indispensable and extremely important to study the regional macroeconomic effects of infrastructure both theoretically and empirically.

## 2.3 Economic Growth Theories

Before the concept of infrastructure was introduced to the field of economics by some development economists in the 1950s, infrastructure as a whole had not been considered as a separate topic to be studied in the context of the formulation and testing of economic growth theories. However, some important components of infrastructure, which includes

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[8]Economies of scale refers to the situation in which the cost to a company of producing or supplying each additional unit of a product (marginal cost) decreases as the volume of output increases, the detailed discussion of the concept can be found in most economic textbooks.

ports and transportation in particular, had been regarded to be highly related to wealth accumulation and production distribution.

With the geographical discoveries of a new continent and new trading routes from the late 15th century to the early 16th century, such infrastructures as ports and shipping, as a method for wealth accumulation, were found to be highly related to commercial trading and industrial investments. Moreover, following the pioneering work by von Thunen (1826) in location theory, Alfred Weber (1929), Edgar Hoover (1937), Melvin Greenhut (1956) and Walter Isard (1956), formal mathematical models for optimal industrial location decision making were developed, in which the total costs of production and transportation were considered simultaneously to determine the optimal production location. For the first time as these model formulations were developed, transportation cost was explicitly introduced into general economic analysis, which directly lead to the recognition of transportation infrastructures in economic growth and development thereafter. Of course, it should not be forgotten that most economists[9] before the 1950s emphasized particularly the function and role a nation may undertake in constructing and maintaining public facilities and public projects when discussing issues of infrastructure and the economic effects of infrastructure was seldom touched.

Since the 1950s when the concept of infrastructure was put forward by some development economists, the economic effects of infrastructure have been studied in a variety of economic growth and development theories, ranging from theories of development economics and neoclassical growth theory to endogenous growth theories.

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[9]These economists include Smith, Say , Mill and others.

- **Theories of Development Economics**

Development economics is a branch of economics that mainly studies the economic issues of the development process in developing countries[10], relatively poor countries or countries with relatively low standards of living on average. The main focus of development economics is to create theories and find methods of promoting economic growth and then improving levels of living for the general population in developing countries. Like many other branches of economics, both qualitative and quantitative methods are used in development economics. However, a significant feature of development economics, differentiating it from other fields of economics, is that social and political strategies are generally incorporated into the theories of development economics and particular plans for economic growth and development in developing countries are then devised (Todaro, Michael and Stephen S., 2006).

Infrastructure, the concept of which was first created by development economists in the 1950s, plays an extremely important role in promoting economic growth and development of developing countries in development economics. Specifically, most development economists proposed that infrastructure investment and productive investment are two interactive components of promoting economic growth and development. However, these economists mainly differ in their opinions on the priority sequence between infrastructure investment and productive investment.

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[10]Developing countries are largely located in such geographical areas as Sub-Saharan Africa, South Asia, and Latin America with some relatively poor countries in East Asia, Central Asia, Eastern Europe, and Middle East and North Africa.

Development economist Albert O. Hirschman (1958) proposed his famous theory of unbalanced growth, which states that the real bottleneck for economic development is not the lack of capital, but the shortage of entrepreneurial abilities. As to the prevalent lack of entrepreneurial abilities in most developing countries, some measures of incentives and pressure should be adopted to ensure the required optimal decisions for economic development may be attained. When it comes to investment choices and strategies in unbalanced growth theory, it is argued that investments should not be spread evenly but concentrated in those projects that can induce additional investments without being too demanding on entrepreneurial abilities. Therefore, under the precondition that a certain amount of infrastructure (Social Overhead Capital, SOC) necessary for a minimum Directly Productive Activities (DPA) is provided, Hirschman (1958) proposed[11] that investments in Directly Productive Activities (DPA) must precede investments in infrastructure (Social Overhead Capital, SOC) to ensure economic growth and development for the main reason that more induced DPA investments can be obtained in this situation.

Specifically, the viewpoint of Hirschman (1958) can be explained as follows. In those developing countries where entrepreneurial abilities and motivations for economic development are deficient, prior investments in infrastructure, which may lead to excess SOC capacity, can only invite rather than compel the DPA investments. By contrast, prior investments in DPA, which may lead to a SOC shortage capacity, can result in strong

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[11]Hirschman (1958) stated that induced investments via SOC (Social Overhead Capital) shortage capacity are higher than those via SOC excess capacity for economic growth and development in developing countries to express the similar idea.

22

pressures and attempts to remedy the current deficiencies in SOC and even determine the appropriate investments for SOC and its location. Therefore, in situations where motivations for economic development are inadequate, Hirschman (1958) concluded that it seems less risky and more economical to rely on development from SOC shortage capacity rather than from SOC excess capacity.

Paul Rosenstein-Rodan (1961), another influential development economist, also attached great importance to infrastructure investment in his famous theory of the big push, which is based on a series of assumptions of certain indivisibilities and non-appropriabilities in production functions and is thus a theory of investment. As to the issue of the allocation of investment, Paul Rosenstein-Rodan (1961), who held a completely opposite view from Albert O. Hirschman (1958), proposed that infrastructure (social overhead capital) must be the preferred investment rather than directly productive investments to ensure rapid economic growth and development in under-developed countries. Because of the indivisibilities[12] and external economies of infrastructure (social overhead capital), its services are indirectly productive, cannot be imported, and are available only after long periods with its most important products created in other industries. Therefore, as Paul Rosenstein-Rodan suggested (1961, p.61), "a high initial investment in social overhead capital must either precede or be known to be certainly available in order to pave the way for additional more quickly yielding directly productive investments".

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[12]Rosenstein-Rodan (1961) proposed four kinds of indivisibilities: (1) indivisible (irreversible) in time; (2) high minimum durability in equipment (lumpy); (3) long gestation periods; (4) an irreducible minimum infrastructure industry mix is required.

Development economist W.W. Rostow (1960) also emphasized the extremely importance of infrastructure in his famous stage theory of economic growth, which defines five basic stages of economic growth: traditional society, preconditions for take-off, take-off, the drive to maturity and the age of high mass consumption. By arguing that "the creation of the preconditions for take-off was largely a matter of building social overhead capital – railways, ports and roads" (Rostow, 1960: 17), Rostow (1960) emphasized that infrastructure should be intensively constructed in the second stage of the preconditions for take-off before large-scale productive investments can be made in following stages, which makes his argument similar to that of Paul Rosenstein-Rodan (1961). Moreover, Rostow (1960) also emphasized the three characteristics[13] of infrastructure (SOC) and argued that infrastructure industry is the basis for the development of other productive industries.

- **Neoclassical Growth Theory**

In the neoclassical growth model developed by Solow (1956) and Swan (1956), a general equilibrium model is established to study what factors might be capable of affecting or even determining the long-run economic growth measured by the growth rate of per capita output based on a series of assumptions concerning the production function, market conditions and others[14]. Here, an important assumption is that the three factors of population growth rate, technological growth rate and household savings rate are all given and therefore exogenous to the economic model itself.

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[13]Long periods of gestation and pay-off, the lumpiness, are the indirect routes of pay-off.
[14]Here I will not address these assumptions in detail since these can be found in any Macroeconomics textbook.

Based on the assumptions discussed before, the Solow-Swan model predicts that neoclassic economic growth will enter into a steady state, in which the growth rate of various quantities is constant. Furthermore, in this steady state, the growth rates of per capita capital, per capita consumption and the per capita output, which cannot be affected by any variables assumed endogenous to the model, should all equal the exogenous technological growth rate[15]. Finally, it should also be noted that any one-time change in the level (not the growth rate) of either endogenous or exogenous variables in the model do not affect the steady-state growth rates of per capita capital, consumption and output, which are all equal to the technological growth rate exogenous to the model. In summary, the neoclassical Solow-Swan growth model predicts that exogenous technological change is the only source of growth, which means that the rate of productivity and output growth can be raised to a higher rate only through the application of a new general-purpose technology. Although Cass (1965), Koopmans (1965), and Diamond[16] (1965) extend traditional Solow-Swan model to make the savings rate endogenous within the model itself, both of them obtain predictions similar to the Solow and Swan model.

From the above, it is clear that none of the neoclassical models, the Solow-Swan model, the Ramsey-Cass-Koopmans model, and the Diamond overlapping-generation model, separately considers the economic effects of infrastructure or public capital, which is instead considered to be included in the "technological changes". With the emergence and popularity of the neoclassical economic growth models and theories, public capital (total

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[15]It should be noted that all the level values of capital, consumption and output grow at the rate of the sum of the population growth and technological growth rates.

[16]Diamond (1965) extends the Ramsey-Cass-Koopmans model to obtain the Diamond overlapping-generation model, which assumes there is a continual entry of new households into the economy.

capital employed in the public sector) was separately considered and theoretically integrated into the neoclassical growth theory by Arrow and Kurz (1970).

Specifically, Arrow and Kurz (1970) extended the aggregate production function to include the stock of public capital as another input apart from labor and private capital. The new aggregate production function is specified as follows:

$$Y(t) = F(K_p(t), K_g(t), e^{rt} L(t)), \quad (2.1)$$

Where F is a concave production function and homogeneous of degree 1, t is the time and r is the percentage rate of technological progress with Kp(t), Kg(t) and L(t) denoting private capital stock, public capital stock and labor supply accordingly. Arrow and Kurz (1970) then further related the determination of the optimal resource allocation between private and public sectors to the goal of getting and keeping the whole economy functioning on an optimal growth path.

- **Endogenous Growth Theory**

Although the Ramsey-Cass-Koopmans and Diamond overlapping-generation models do not reject the Solow and Swan endogenous growth theory, they revive the methodology to study macroeconomics in terms of micro-foundations in which the dynamics of macroeconomics are determined by the rational decisions of individual entities at the microeconomic levels.

From the above discussion, it is true that the savings rate has been treated as endogenous in the Ramsey-Cass-Koopmans and Diamond overlapping-generation models, but they

still face the same challenge as the standard neoclassical growth model (Solow and Swan growth model): all of the three growth models are unable to explain the determinants of long-term economic growth satisfactorily since the economy will converge to a steady state with a zero growth rate of output per capita without technological change under the predictions of the three models. As to the three neoclassical growth models discussed above, the main reason for the zero growth rate of output per capita occurs without technological change is that the return to capital is diminishing. Therefore, almost all endogenous growth theories developed subsequently attempt to resolve the dilemma of diminishing returns to capital. Two kinds of methods are derived, which also lead to the formations of two classes of endogenous growth theory. Specifically, one way is to construct the AK model with the absence of diminishing returns to capital. In reality, the AK model can mainly be interpreted and realized in the following two ways. First, spillover effects are considered in economic growth models with the consideration of a broad concept of capital; second, governmentally provided public services, which are highly related to public infrastructure, are another possible interpretation of the AK form. The other way out of the puzzle is to argue that technological progress is the only way to avoid diminishing returns to capital in the long run, which necessarily requires that the technological progress should be explained within the growth model itself. Since the purpose of this part of the dissertation is to review the economic growth theories related to infrastructure, the AK model with its two different interpretations will be discussed.

As to the AK model, the term AK comes from the simplest form of the model's production function:

$Y = AK$  (2.2)

where A is a positive constant representing the economy's level of technology and K is the economy's stock of capital. Here, the diminishing returns to capital are absent and the returns to capital are always actually constant. When the AK technology is combined with optimizing decisions of households and firms, the simple AK model predicts that the economy in the model can produce a positive long-run growth rate of per capita output even when the technological progress is zero. More importantly, the long-run growth rate of per capita output is endogenously determined by the behavioral parameters with the model itself and the changes in these related endogenous behavioral parameters will have permanent effects on the long-term growth rate of per capita output. In other words, the long-term economic growth rate of per capita output can be endogenously determined and sustained by the behavioral parameters within the model even if the technological progress is exogenous and set to zero.

The first interpretation of the AK model is to consider the central role played by the spillover effects as well as a broad concept of capital in economic growth models (Romer 1986, and Lucas 1988). Romer (1986) constructs a new model of endogenous growth in which the assumptions of Arrow's learning-by-doing (1962) and knowledge spillovers play a central role in escaping the diminishing returns to capital, which is only conceptually represented in the AK model. Specifically, the essence of Arrow's learning-by-doing assumption is that firms can improve productive technologies and then can gain complete control over new technology through their experiences in production (i.e. new

knowledge or technology is a side product of the investment for production). And the assumption of knowledge spillover is that the discovered new knowledge by each firm during production can spill over instantly and costless across the whole economy, which implies that any technological improvement in a single firm simultaneously corresponds to the same improvement in the whole economy. Romer's model (1986) still predicts that the long-term growth rate of per capita output is constant and can be endogenously determined by the behavioral parameters within the model even if the exogenous technological change rate is zero. Therefore, Romer's model (1986) also confirms that long-term per capita growth can be achieved and sustained even without exogenous technological change if the absence of diminishing returns to capital is explicitly considered in a growth model. Actually, in the Romer (1986) model it is the non-rivalry of knowledge or idea that eliminates the tendency of diminishing returns to capital.

Compared to the Romer (1986) model that avoids the emergence of diminishing returns to capital by considering and modeling the definition of broadened capital to include physical capital and knowledge capital, human capital growth models use the definition of broadened capital to include physical capital and human capital and therefore avoid diminishing returns to capital. In the Lucas (1988) analysis, knowledge is considered to be created and transmitted through human capital. Meanwhile, the spillover effects involve interactions among smart people in the Lucas (1988) model rather than among firms in Romer (1986) model. The model developed by Uzawa (1965) and used by Lucas (1988) is a classical human capital growth model. It considers the situation in which physical and human capitals are produced by different technologies separately in the two

29

sectors of production and education. The Uzawa-Lucas model finds that the imbalances between physical and human capital could create an asymmetrical effect on the long-term growth rate of per capita output: the growth rate for per capita output will increase with the increase of the imbalances between physical and human capital if human capital is relatively abundant and decreases with the size of the imbalances if human capital is relatively scarce. Therefore, in the human capital growth model it is the production of human capital that prevents the emergence of diminishing returns to capital and then leads to long-term per capita output growth even if the exogenous technological progress is zero.

Another possible source and interpretation of the AK model is the government's public services, about which the government's choices determine the coefficient A in the AK model and thus the long-term economic growth rate. Barro (1990) proposed that tax-financed public services can prevent diminishing returns of capital and therefore result in endogenous economic growth as in the AK model studied earlier. Specifically, Barro (1990) introduces the flow of the government's spending of goods and services into a Cobb-Douglas production function as pure public goods and the specification for firm i is:

$$Y_i = AL_i^{(1-a)} K_i^a G^{(1-a)} \quad (2.3)$$

where 0<a<1. This equation implies that production for each firm exhibits constant returns to scale in the private inputs: labor ($L_i$) and capital ($K_i$). Meanwhile, the form of production function assumes constant returns in $K_i$ and G for fixed $L_i$, which implies that

the economy is capable of endogenous growth. By supposing that the government finances its public services with lump-sum taxes, Barro (1990) further gets to the equation of the common economic growth rate[17], which verifies and confirms the argument that the non-rival public services with costless spread over additional users are able to produce steady-state endogenous growth in the economy. From the equation of common growth rate, it also shows that there is a nonlinear relationship between public spending and private output. When government spending increases from a small to moderate ratio of government spending to total output, the marginal productivities of capital and labor are increased and likewise the growth rate of private output. However, the marginal productivities of capital and labor will decrease and does the growth rate of private output if the ratio of government spending to total output is very large.

Aschauer (2000) extends the Barro model (1990) by focusing on the productive services of public capital rather than on the flow of government spending. Specifically, Aschauer (2000) introduces the stock of public infrastructure capital as well as private capital and labor into a Cobb-Douglas production function, which exhibits constant returns to scale across private and public capital inputs. After some mathematical deductions, Aschauer (2000) also develops a non-linear theoretical relationship between public capital and economic growth for the purpose of finding the growth-maximizing ratio of public capital to private capital. Furthermore, it is found that permanent changes in public capital bring forth permanent changes in economic growth.

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[17]The detailed equation for the common growth rate is not provided here. It can be found in Barro (1990, P108).

## 2.4 Summary

Although infrastructure can be understood from both the narrow and wide perspectives, the narrow definition of infrastructure, which mainly includes services from public utilities, public works and other transportation sectors (World Bank, 1994), is used in this dissertation. Meanwhile, the research also emphasizes the characteristics of infrastructure as a kind of capital (i.e., public capital). The main characteristics of infrastructure include low mobility, substantial initial investments, low marginal cost of adding an extra user, external economy, natural monopoly and coexistence of public and private ownership. The important economic growth theories related to infrastructure include theories of development economics, neoclassical growth theory and endogenous growth theory, all of which confirm the important effects of infrastructure on economic growth and development.

# 3 Public Infrastructure in China

This chapter is a review of some important issues on public infrastructure in China. The first section provides an overview of infrastructure development in China. The second attempts to compare China's infrastructure development with that of other countries in the world. The third section analyzes the time structure, sectoral structure and regional structure of infrastructure investment in China respectively. The fourth section summarizes the important institutional and policy factors behind the rapid growth of public infrastructure in China. The final section concludes.

## 3.1 An Overview of Infrastructure Development in China

Modern infrastructure in China began with the construction of Song-Hu (Wusong-Shanghai) railroad in 1876. Before 1949 when the People's Republic of China was established, modern infrastructure (especially transportation infrastructure) had been developed very slowly in China: the total length of railroads countrywide was 360 kilometers in 1894, 9600 kilometers in 1911 and 13000 kilometers in 1927[18].

After 1949, infrastructure construction in China developed rapidly. Table 1 gives some key indicators of infrastructure in China from 1952 to 2006, which includes such aspects

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[18]See Editorial Group, Department of Economics, Renmin University of China, *Modern Chinese Economic History*, People's Publishing House, Beijing, 1979

as transportation (roads, railways, aviation routes and pipelines), telecommunications (total telephones and telephones per 100 persons) and energy production (electricity outputs). The length of roads increased about twenty-seven-fold from 126,700 kilometers in 1952 to 3,457,000 kilometers in 2006. The length of railways increased from 22,900 kilometers in 1952 to 77,100 kilometers in 2006. The length of civil aviation increased from 13,100 kilometers in 1952 to 2,113,500 kilometers in 2006, a one-hundred-and-sixty-one-fold increase. The number of fixed telephones at year-end increased from 353,700 in 1952 to 367,786,000 in 2006, an increase of one thousand and forty times. Electricity output increased from 7.3 billions of Kilowatt-hours in 1952 to 2,876.5 billions of Kilowatt-hours in 2006, a three-hundred-and-ninety-four-fold increase.

*Table 1: China's Infrastructures, 1952-2006*

| Year | Roads Total (1000 km) | Railway Total (1000 km) | Civil Aviation (1000 km) | Petroleum & Gas Pipeline (1000 km) | Local Telephone (including mobile phone) per 100 Persons | Fixed Telephone at Year-end (1000 subscribers) | Electricity Output (Billion kwh) |
|------|------|------|------|------|------|------|------|
| 1952 | 126.7 | 22.9 | 13.1 | - | | 353.7 | 7.3 |
| 1957 | 254.6 | 26.7 | 26.4 | - | | 664.5 | 19.3 |
| 1962 | 463.5 | 34.6 | 35.3 | 0.2 | | 1552.1 | 45.8 |
| 1965 | 514.5 | 36.4 | 39.4 | 0.4 | | 1263.3 | 67.6 |
| 1970 | 636.7 | 41.0 | 40.6 | 1.2 | | 1311.5 | 115.9 |
| 1975 | 783.6 | 46.0 | 84.2 | 5.3 | | 1692 | 195.8 |
| 1978 | 890.2 | 48.6 | 148.9 | 8.3 | | 1925.4 | 256.6 |
| 1980 | 883.3 | 49.9 | 195.3 | 8.7 | 0.43 | 2140.7 | 300.6 |
| 1981 | 897.5 | 50.2 | 218.2 | 9.7 | 0.45 | 2220.9 | 309.3 |
| 1982 | 907.0 | 50.5 | 232.7 | 10.4 | | 2342.5 | 327.7 |
| 1983 | 915.1 | 51.6 | 229.1 | 10.8 | | 2507.6 | 351.4 |

34

| 1984 | 926.7 | 51.7 | 260.2 | 11.0 | | 2774.3 | 377.0 |
|------|-------|------|-------|------|------|--------|-------|
| 1985 | 942.4 | 52.1 | 277.2 | 11.7 | 0.6 | 3120.3 | 410.7 |
| 1986 | 962.8 | 52.5 | 324.3 | 13.0 | 0.67 | 3503.8 | 449.5 |
| 1987 | 982.2 | 52.6 | 389.1 | 13.8 | 0.75 | 3907.2 | 497.3 |
| 1988 | 999.6 | 52.8 | 373.8 | 14.3 | 0.86 | 4726.9 | 546.7 |
| 1989 | 1014.3 | 53.2 | 471.9 | 15.1 | 0.98 | 5680.4 | 586.5 |
| 1990 | 1028.3 | 53.4 | 506.8 | 15.9 | 1.11 | 6850.3 | 621.2 |
| 1991 | 1041.1 | 53.4 | 559.1 | 16.2 | 1.29 | 8450.6 | 677.6 |
| 1992 | 1056.7 | 53.6 | 836.6 | 16.3 | 1.61 | 11469.1 | 753.9 |
| 1993 | 1083.5 | 53.8 | 960.8 | 16.4 | 3.30 | 17331.6 | 938.5 |
| 1994 | 1117.8 | 54.0 | 1045.6 | 16.8 | 3.20 | 27295.3 | 928.1 |
| 1995 | 1157.0 | 54.6 | 1129.0 | 17.2 | 4.66 | 40705.6 | 1007.7 |
| 1996 | 1185.8 | 56.7 | 1166.5 | 19.3 | 6.33 | 54947.4 | 1080.0 |
| 1997 | 1226.4 | 57.6 | 1425.0 | 20.4 | 8.11 | 70310.3 | 1135.5 |
| 1998 | 1278.5 | 57.6 | 1505.8 | 23.1 | 10.53 | 87420 | 1166.2 |
| 1999 | 1351.7 | 57.9 | 1522.2 | 24.9 | 13.00 | 108720 | 1239.3 |
| 2000 | 1402.7 | 68.7 | 1502.9 | 24.7 | 20.10 | 144829 | 1355.6 |
| 2001 | 1698.0 | 70.1 | 1553.6 | 27.6 | 25.90 | 180368 | 1471.7 |
| 2002 | 1765.2 | 71.9 | 1637.7 | 29.8 | 33.60 | 214222 | 1640.5 |
| 2003 | 1809.8 | 73.0 | 1749.5 | 32.6 | 42.16 | 262747 | 1910.6 |
| 2004 | 1870.7 | 74.4 | 2049.4 | 38.2 | 50.03 | 311756 | 2203.3 |
| 2005 | 3345.2 | 75.4 | 1998.5 | 44.0 | 57.22 | 350445 | 2500.3 |
| 2006 | 3457.0 | 77.1 | 2113.5 | 48.2 | 63.40 | 367786 | 2865.7 |

Source: China Statistical Yearbook (1989-2007); China Compendium of Statistics, 1949 -2004.

Infrastructure development in China was different before and after the economic reform initiated in 1978. Table 2 compares the average growth rate of some key infrastructure types between the period of 1952-1978 and the period of 1978-2006. The growth rates of

those traditional types of infrastructure (i.e., roads, railways, Petroleum & Gas Pipeline, electricity output) were slower from 1978 to 2006 than from 1952 to 1978, while the growth rates of those higher-technology-oriented infrastructures (i.e., aviation routes, local telephones per 100 persons) were almost equal or faster from 1978 to 2006 than from 1952 to 1978. Table 2 also compares the growth rates between infrastructure and real GDP per capita. It is shown that the conventional infrastructures (i.e., roads, railways, Petroleum & Gas Pipeline) grew slower than the real GDP per capita after 1978.

The growth rates of those key types of infrastructures in the three sub-periods of 1978-1990, 1990-1998 and 1998-2006 are also available from Table 2. It can be shown that the pace of those key types of infrastructure development has been on the rise since 1978, which is especially prominent for those traditional infrastructures from 1998 to 2006. In contrast, the growth rate of those higher-technology-oriented infrastructures has been very high during the period of 1990-1998 and then declined afterwards. Moreover, it should be noted that almost all the key infrastructure types in Table 2 (except for railways and aviation routes) grow faster than the real GDP per capita during the period of 1998-2006.

*Table 2: Growth Rate of Some Key Infrastructures (Percentage), 1952-2006*

|  | **1952-1978** | **1978-2006** | **1978-1990** | **1990-1998** | **1998-2006** |
|---|---|---|---|---|---|
| **Roads** | 8.59 | 5.63 | 1.43 | 2.61 | 14.09 |
| **Railways** | 3.19 | 1.57 | 1.06 | 1.75 | 2.01 |
| **Aviation Routes** | 11.21 | 10.50 | 11.22 | 14.46 | 4.61 |
| **Petroleum&Gas Pipeline** | 22.23 | 7.20 | 7.05 | 4.94 | 10.14 |

| Local Telephones per 100 persons | 6.52[19] | 21.41 | 11.32 | 36.08 | 20.43 |
|---|---|---|---|---|---|
| **Electricity Output** | 13.69 | 9.10 | 7.67 | 8.14 | 10.92 |
| **Real GDP per Capita** | 4.50 | 8.56 | 7.73 | 8.99 | 8.44 |

Source: China Statistical Yearbook (1989-2007); China Compendium of Statistics, 1949 -2004.

## 3.2 Public Infrastructure: a World Comparison

According to the income level classification criteria designed by the World Bank in the World Development Indicator (WDI) 2003, lower middle income economies (LMC) are defined as those in which 2001 Gross National Income (GNI) per capita[20] was between $745 and $2,975[21]. In 2001, China's GNI per capita is $1000, about $100 higher than the average of the lower-middle-income economies ($895.6961) and less than one fifth of the world average ($5226.978). Moreover, even when the Purchase Power Parity (PPP) is considered, China's GNI per capita, PPP (current U.S. dollar) in 2001 is $2560, almost equal to the average of the lower-middle-income economies ($2568.09) and less than 40 percent of the world average ($7131.09). Therefore, China has been a typical lower middle income country in the world.

Table 3 below compares the main infrastructure indicators among China, the world average and three primarykinds of economies classified by the World Bank (low income, middle income and high income economies). Two conclusions can be drawn from the

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[19]Average Growth Rate from 1959-1978.

[20]GNI per capita refers to that of Atlas method (current US $) if not stated otherwise.

[21]The other three economies are low income economies, upper middle income economies and high income economies, with GNI per capita being $745 or less, between $2976 and $9205, and $9206 or more respectively.

table. First, it cannot be denied that China's public infrastructures have achieved a great expansion in the past 20 years. In 2000, 97% of Chinese people had access to the electricity network, which was only 2 percent lower than the corresponding number for the high income economies. In contrast, the average number for the world and the middle income economies is only 60% and 85%. Second, in terms of the teledensity (telephone subscribers per 1000 people), this indicator in China increased from 6 in 1990 to 424 in 2003, while the number for the world average and the lower middle income economies during the same period only increased from 142 to 526 and 54 to 319 respectively. Third, it is evident that the main aspects of China's public infrastructures have been unequally developed. Although the access to electricity network and the teledensity in China have approached or exceeded the world average, the access to improved water sources and the road density in China have been still below those of the lower middle income economies and the world average.

*Table 3: Infrastructure Comparison Worldwide*

| Unweighted Averages | Access to Electricity Network( % of Population) | Access to Improved Water Sources (% of Population) | | Teledensity (total telephone subscribers / 1000 people) | | | Road Density (road-km / 1000 people) | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 2000 | 1990 | 2002 | 1990 | 1995 | 2003 | 1990 | 1995 | 2005 |
| China | 97 | 70 | 77 | 6 | 36 | 424 | 1.04 | 1.21 | 2.57 |
| World | 60 | 77 | 80 | 142 | 187 | 526 | 6.6 | 6.67 | 9.52 |
| Low Income | 31 | 56 | 65 | 17 | 19 | 76 | 3.33 | 3.24 | 2.71 |
| Middle Income | 85 | 86 | 89 | 94 | 137 | 496 | 6.54 | 6.66 | 8.6 |
| *Lower Middle Income* | 82 | 81 | 85 | 54 | 81 | 319 | 5.26 | 5.18 | 4.44 |
| *Upper Middle Income* | 87 | 91 | 93 | 134 | 193 | 672 | 7.82 | 8.13 | 12.75 |
| High Income | 99 | 99 | 99 | 401 | 524 | 1248 | 10.49 | 10.83 | 11.96 |

Source: Calculation based on data from World Bank (2006)

In the past 30 years, telecommunications infrastructure has experienced rapid developments and received great attentions worldwide among the main components of public infrastructure. The development level of telecommunications infrastructure has become one of the most important indicators to evaluate the overall development level of public infrastructure in a country. More importantly, the positive correlation between telecommunications infrastructure development and overall economic development has been well studied and established (e.g. Hardy, 1980). Here, a telecommunications infrastructure indicator (represented by teledensity), a typical representative component of public infrastructure, is regressed against an economic development indicator (represented by GDP at purchasing power parity per capita) to demonstrate China's public infrastructure development compared with its economic development level.

Specifically, the following equation is estimated by regressing the logarithmic values of the teledensity data (LTELD) against the logarithmic values of GDP PPP per capita in constant 2005 international dollar (LGDP) data in the years of 1985, 1990, 1995, 2000 and 2003 respectively:

$$LTELD_{it} = \alpha + \beta\, LGDP_{it} + \epsilon_{it} \quad (3.1)$$

where $\alpha$ is the intercept and $\varepsilon_{it}$ is the error term for country i at year t. Moreover, since China is a lower middle income country, only countries in this category with complete data are included in the data set for the regression, which enables comparisons precisely between China and the lower middle income economy as a whole. The regression results

are given in Table 4 below, with a statistical significance of 99 percent for all the estimated coefficients in all five years.

*Table 4: Teledensity vs. GDP per capita: regression results*

|  | **1985** | **1990** | **1995** | **2000** | **2003** |
|---|---|---|---|---|---|
| **α** | -6.30 (-4.42) | -6.76 (-5.01) | -4.43 (-2.84) | -4.31 (-2.76) | -3.25 (-1.82) |
| **β** | 1.16 (6.66) | 1.26 (7.71) | 1.04 (5.51) | 1.10 (5.93) | 1.05 (4.96) |
| **R²** | 0.56 | 0.59 | 0.41 | 0.44 | 0.42 |
| **Observations** | 37 | 44 | 46 | 46 | 36 |

Note: t-statistics in bracket.

Source: Calculation based on data from World Bank (2006)

*Table 5: Actual and predicted teledensity in China*

|  | **1985** | **1990** | **1995** | **2000** | **2003** |
|---|---|---|---|---|---|
| GDP per capita | 813 | 1099 | 1847 | 2664 | 3394 |
| Predicted Teledensity | 4.46 | 7.77 | 29.27 | 81.28 | 190.32 |
| Actual Teledensity | 3 | 6 | 36 | 178 | 424 |
| Difference (actual - projected) | -1.46 | -1.77 | 6.73 | 96.72 | 233.68 |

Note: teledensity is defined as the total telephone subscribers per 1000 people

Source: Calculation based on data from World Bank (2006)

Table 5 compares the actual teledensity with the predicted teledensity in China based on the regression model for the lower middle income economies. From the table, China's actual teledensity values are below corresponding predicted values in the year of 1985 and 1990, but the fact is reversed in the year of 1995, 2000 and 2003. In particular, China's actual teledensity values are more than twice the corresponding projected values in 2000 and 2003. Therefore, it is evident that China has successfully outperformed the overall lower middle income economy in terms of telecommunications infrastructure

development since 1995, which has also been taken as an indicator of rapid development of public infrastructure in China to some extent.

## 3.3 Structure Analysis of Infrastructure Investment in China

As demonstrated previously, the public infrastructure in China has achieved remarkable developments in the past 20 years. However, it has been widely believed that public infrastructure development is highly positively related to the corresponding infrastructure investments. More infrastructure investments generally lead to more infrastructure developments. More importantly, since the dissertation emphasizes the characteristics of infrastructure as a kind of capital, infrastructure investments[22] in China are given more attentions and studied in greater details below.

### 3.3.1 Time Structure of Infrastructure Investment in China

From 1985 to 2007, the annual infrastructure investments in China have grown from 35.13 billion yuan to 2362.16 billion yuan, over 66 times increase during the period (Figure 1).

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[22]Due to data limitation, infrastructure investments only include investments in the following two sectors from 1985 to 2007: (1) Transport, Storage, Post and Telecommunication Services; and (2) Production and Supply of Electricity, Gas and Water; Data are calculated at current prices.
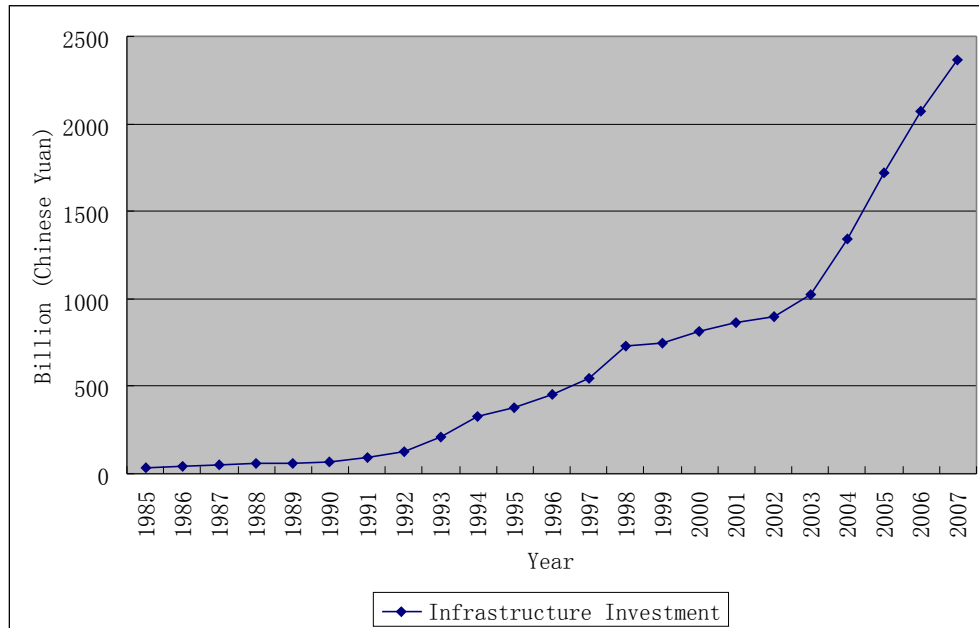
Source: Based on Statistics on China's Statistical Yearbook 1989-2008

*Figure 1: Infrastructure Investment in China, 1985-2007*

Meanwhile, the share of infrastructure investment in the national nominal GDP has taken an upward trend, increasing from 3.90% in 1985 to 9.47% in 2007 (Figure 2). Finally, the growth rates of infrastructure investment and nominal GDP exhibit a strong periodic relationship (Figure 3). During most of the time in the 1990s[23], the infrastructure investment increased faster than the nominal GDP, which is also true for the period of 2003 – 2007.

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[23]The year of 1999 is an exception when the growth rate of nominal GDP (6.25%) is higher than that of infrastructure investment (3.07%).
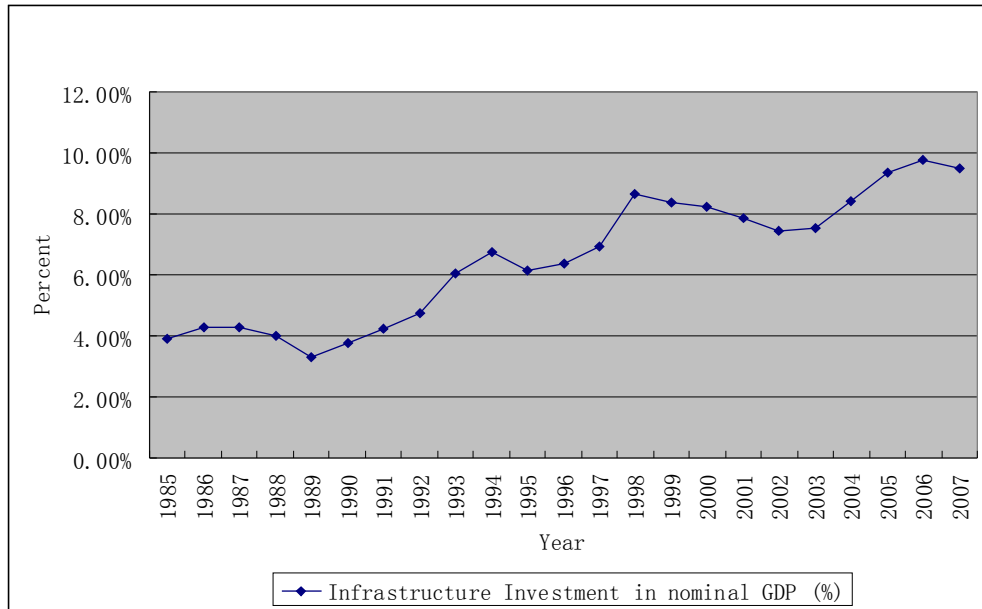
Source: Based on Statistics on China's Statistical Yearbook 1989-2008

*Figure 2: Infrastructure Investment as a Percentage of Nominal GDP in China, 1985-2002*
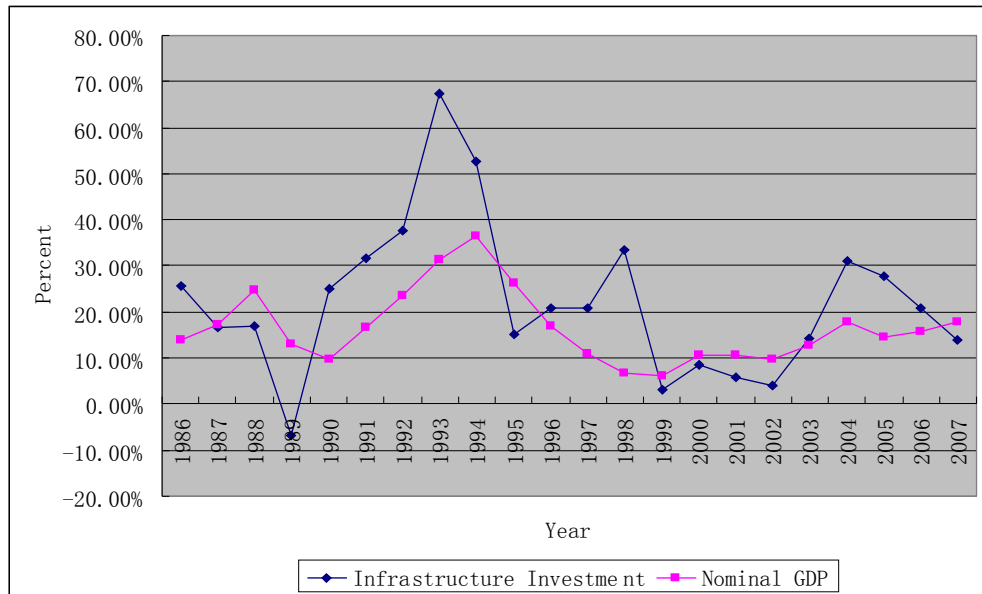


*Source: Based on Statistics on China's Statistical Yearbook 1989-2008*

*Figure 3: Growth rate of Infrastructure Investment and Nominal GDP in Chin, 1986-2007*

## 3.3.2 Sectoral Structure of Infrastructure Investment in China

The total infrastructure investment in China can be disaggregated into the following two parts: the first is the investment in the sector of Transport, Storage, Post and Telecommunication services (TSPT) and the second is the investment in the sector of Production and Supply of Electricity, Gas and Water (PSEGW). From 1985 to 2007, infrastructure investment in both sectors have been increasing rapidly, with investment in the TSPT sector always higher than that in the PSEGW sector (Figure 4). Moreover, the growth rate of infrastructure investment in the TSPT sector was nearly always higher than that in the PSEGW sector in the 1990s but otherwise in the other years of the periods 1986 – 2007 (Figure 5).
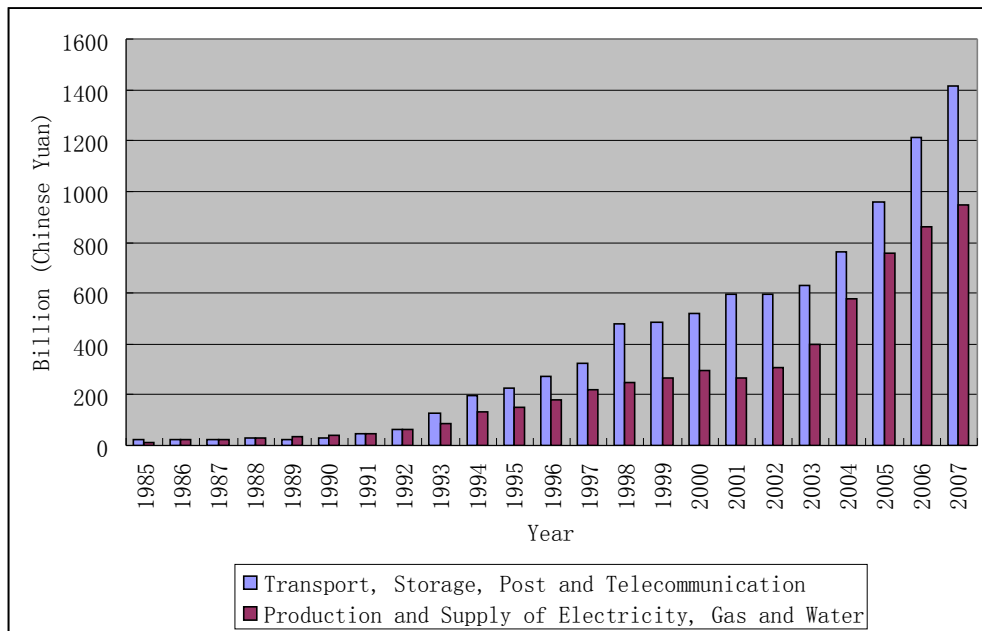


Source: Based on Statistics on China's Statistical Yearbook 1989-2008

*Figure 4: Infrastructure Investments by Sectors in China, 1985-2007*

44
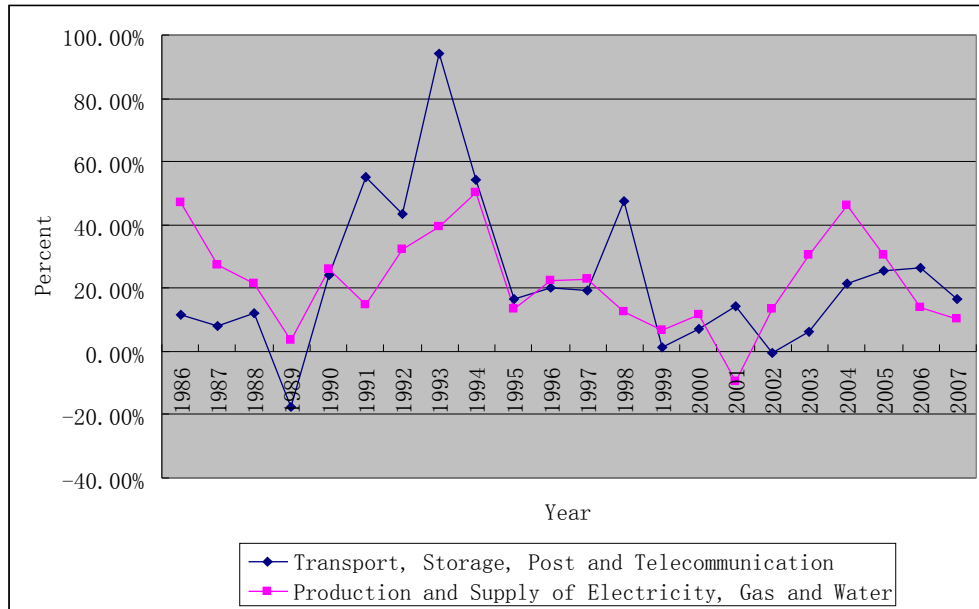
Source: Based on Statistics on China's Statistical Yearbook 1989-2008

*Figure 5: Growth rates of infrastructure Investment by Sectors*

## 3.3.3 Regional Structure of Infrastructure Investment in China

Although infrastructure investments in China have experienced a rapid growth in the past two decades, the distribution of these investments among different regions is quite unbalanced and needs to be discussed in greater detail here.

The Gini coefficient, which is a measure of statistical dispersion originally developed by the Italian statistician Corrado Gini, has been widely used to study inequality and even any distribution in many disciplines. Theoretically, the Gini coefficient ranges from 0 to 1, with 0 corresponding to perfect equality and 1 corresponding to perfect inequality. Here, the Gini coefficients for the provincial distribution of the infrastructure investments are compared with the Gini coefficients for the provincial distribution of incomes to

determine the extent to which the provincial infrastructure investments are compatible with provincial incomes. As Figure 6 shows, the Gini coefficient for the provincial distribution of the investment per capita for the sector of Transport, Storage, Post and Telecommunication services (TSPT) had always been higher than the Gini Coefficient for the provincial distribution of GDP per capita before 1999 although the Gini coefficient for the provincial infrastructure investment exhibited a descending trend. Then from 1999 to 2006, the Gini coefficient was lower than that of provincial GDP per capita. A similar fact also applies to the Gini coefficient for the provincial distribution of the investment per capita for the sector of Production and Supply of Electricity, Gas and Water (PSEGW). Therefore, there had been an obvious regional disparity in infrastructure investments among regions from 1986 to 1998, but the situation has been reversed since 1999.
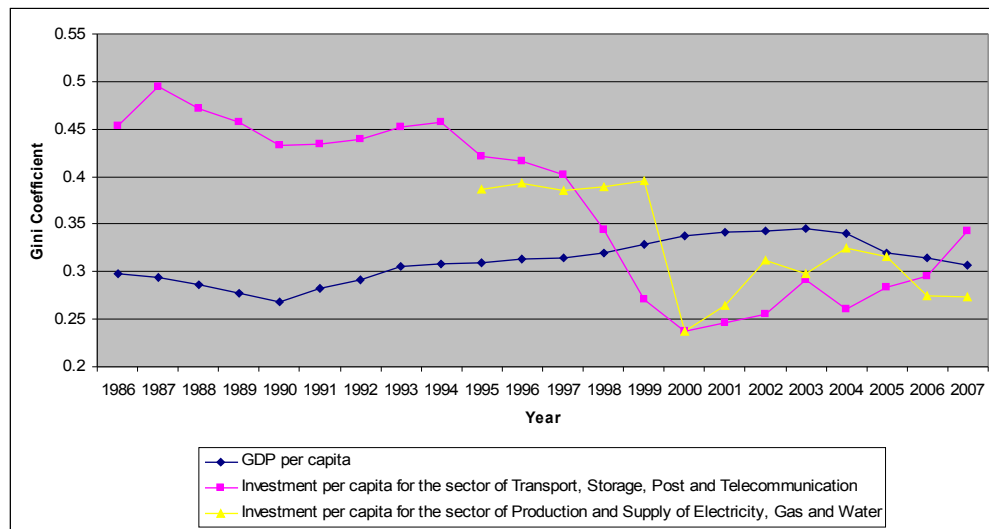


Source: Based on Statistics on China's Statistical Yearbook 1987-2008

*Figure 6: Gini Coefficients of GDP Per Capita and Infrastructure Investment Per Capita among Regions*

46

From the view of economic geography, China has been traditionally divided into three mega-regions - Eastern, Central and Western mega-regions. The Eastern mega-region is composed of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan, twelve provinces and municipalities altogether. The Central mega-region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Huibei and Hunan, nine provinces and autonomous regions altogether. The Western mega-region consists of Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shanxi, Gansu, Qinghai, Ningxia and Xinjiang, ten provinces and autonomous regions altogether[24].

Here, the relationship between mega-regional infrastructure investment and mega-regional GDP is exmined, with an attempt to get some idea of the distribution of mega-regional infrastructure investment in China. For a specific mega-region, the difference between its infrastructure investment per capita and corresponding national average value is compared with the difference between its GDP per capita and corresponding national average value, which can therefore shed light on the mega-regional characteristics of infrastructure investment in China. Table 6 below provides a snapshot of relative infrastructure investments in the sector of Transport, Storage, Post and Telecommunication services (TSPT) across different mega-regions and years in China. For instance, for the Eastern mega-region in 1986, the value of 40.84 means that its investment in TSPT per capita is 40.84 percent more than the corresponding national average value  in 1986 and the value of 28.18 means that its GDP per capita is 28.18

[24]Tibet is excluded and Chongqing is combined with Sichuan for the statistics of the Western macro-region due to data unavailability.

percent more than the corresponding national average value in 1986. Then the value of 12.66, the relative investment density defined here, is just the difference between the two values of 40.84 and 28.18, which indicates that the fixed investment in TSPT for the Eastern mega-region in 1986 is over-allocated (28.18%) relative to its GDP per capita against the national level. As Table 6 shows, the relative investment density in TSPT for the Eastern mega-region has been decreasing consistently, from over-allocated in 1986 to under-allocated in 2007. In contrast, the Central mega-region has experienced a consistent increase in relative investment density. For the Western mega-region, the relative investment density decreased first and then increased.

*Table 6: Relative Investment Densities in the sector of Transport, Storage, Post and Telecommunication services (TSPT) in Different mega-regions, 1986, 1995, 2007 (%)*

|  | 1986 | | | 1995 | | | 2007 | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | (1) | (2) | (1)-(2) | (1) | (2) | (1)-(2) | (1) | (2) | (1)-(2) |
| Eastern | 40.84 | 28.18 | **12.66** | 50.76 | 41.10 | **9.66** | 26.78 | 41.18 | **-14.40** |
| Central | -32.12 | -14.10 | **-18.02** | -36.18 | -24.13 | **-12.06** | -21.40 | -25.38 | **3.98** |
| Western | -26.23 | -32.43 | **6.21** | -38.83 | -40.58 | **1.75** | -19.66 | -41.79 | **22.13** |

(1) refers to the relative difference between mega-regional and national values for infrastructure investment per capita and (2) refers to the relative difference between mega-regional and national values for nominal GDP.

Source: Calculation based on Data on China's Statistical Yearbook 1989-2008

Figure 7 and Figure 8 provide the overall picture of the relative investment densities in the two sectors of TSPT and PSEGW in different mega-regions in the last two decades. For the TSPT sector, the relative investment density in the Eastern region was fairly stable before 1998 and then decreased sharply to negative values after that. Only in recent years has the density increased steadily. On the contrary, both of the relative investment

48

densities in the Central and Western regions have experienced a transition from under-allocated to over-allocated, having increased steadily since 1998 but then decreased since 2003. For the PSEGW sector, the relative investment density in the Eastern region has been descending with negative values occurring all the time. The situation is just the opposite for both of the Central and Western regions, indicating the two regions have consistently received over-allocated investments in the PSEGW sector in the past decade.
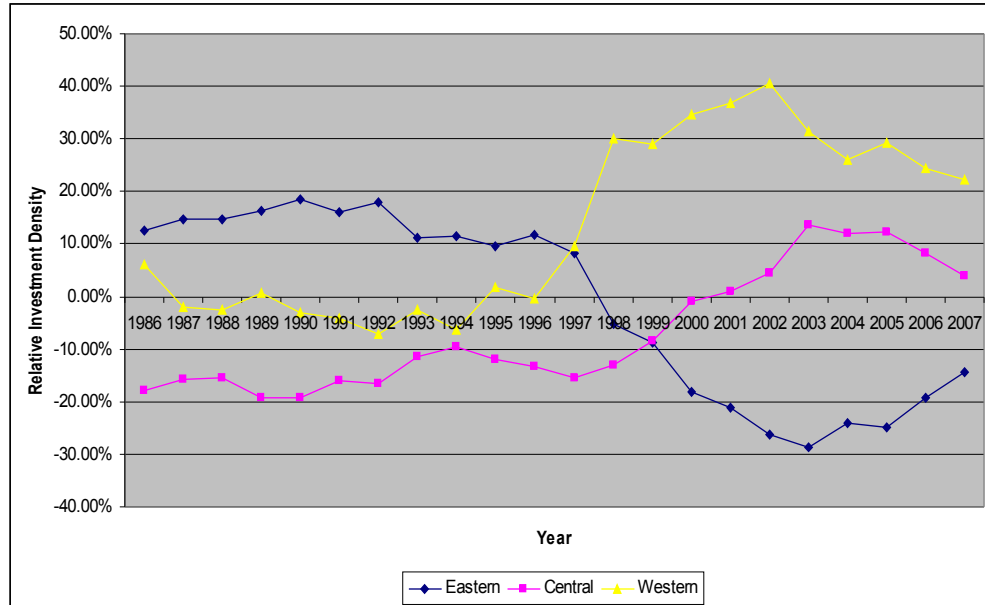


Source: Calculation on Data on China's Statistical Yearbook 1989-2008

*Figure 7: Relative Investment Densities in the sector of Transport, Storage, Post and Telecommunication services (TSPT) across regions,1986-2007*
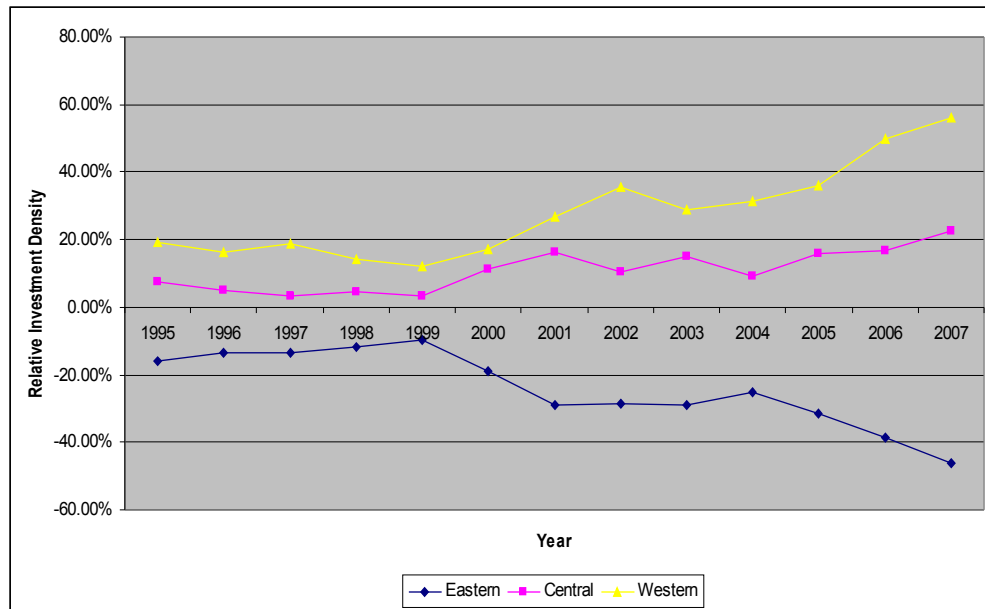
Source: Calculation on Data on China's Statistical Yearbook 1996-2008

*Figure 8: Relative Investment Densities in the sector of Production and Supply of Electricity, Gas and Water (PSEGW) across Regions,1995-2007*

## 3.4 Behind the Rapid Growth of Public Infrastructure in China

Although it is generally accepted that public infrastructure in China has achieved remarkable improvement and development since the 1980s, few efforts have been made to delve into the underlying factors behind the rapid growth and developments of public infrastructure in China. Since it is an important academic and practical issue to thoroughly find and study those potential factors conductive to the rapid growth of public infrastructure in China, this section attempts to shed some light on this issue. Specifically, these factors behind the rapid growth of public infrastructure in China will be analyzed from the following two perspectives of institutional change and policy stimulus.

50

## 3.4.1 Institutional Changes behind the Rapid Growth of Infrastructure in China

The economic impact of political institutions has been fully studied in the last several decades since North and Thomas (1973) first examined economic history from the innovative view of transaction cost. One of the core ideas of the institutional economics argues that a government's ability and commitment to not interfere with private property rights is very important for the country to obtain the capital investments that are indispensable for its rapid long-term economic growth and development. Although this argument may apply best to private investors, it is still applicable to the managers of the public sector who face different incentives to arrange capital for the main reason that the institutional environment can affect these incentives to a greater extent. More importantly, many researchers have demonstrated that a country's institutional environment has a great effect on infrastructure investments in that country (Williamson, 1976; Spiller, 1993; Savedoff and Spiller, 1997).

Meanwhile, many empirical studies also provide strong evidences for this argument (Grandy, 1989; Daniels and Trebilcock, 1994; Crain and Oakley, 1995; Levy and Spiller, 1996; Ramamurti, 1996; Caballero and Hammour, 1998; Henisz and Zelner, 2001 and 2002). Since infrastructure investments generally exhibit a strong inclination of politics as well as economies of scale and scope, they are naturally sensitive to the institutional environment and any changes in these aspects.

In the context of China, the institutional environment also has significant effects on infrastructure investments. The rapid growth and development of China's public infrastructure in the last three decades is due greatly to some important institutional changes that occurred during the same period in China. These institutional changes and their effects on infrastructure investments in China will be briefly addressed below.

- **Reform and Opening-up Strategy in China**

Since the late 1970s, China has experienced one of the most important institutional changes in Chinese history. A series of economic reforms were launched and implemented in China with the core idea being "reform and opening-up". In sharp contrast to the "shock therapy" approach adopted by the former Soviet Union and some emerging economies of Eastern Europe, China took a more gradualist and experimental approach to economic reform. In fact, there was really no blueprint on what Chinese economic reform might be or how it would proceed in the initial period of the economic reform in China. It was not until 1992 when the "socialist market economy with Chinese features" was first manifested at the 14th Party Congress and also endorsed as the ultimate goal of China's reform.

China's economic reform was undertaken through the following phased reforms with different emphases and goals for each phase. For the first phase of the reforms in the late 1970s and early 1980s, the reforms mainly focused on opening international trade, attracting foreign direct investments and establishing the household responsibility system in the agricultural sector of China. For the second phase in the mid 1980s and early

1990s, the reforms attempted to create a market-oriented pricing system and increase the role of markets in resource allocation decisions. For the third phase in the mid 1990s, the reforms involved closing unprofitable state-owned enterprises, resolving insolvency in the state-owned banking systems and developing social security systems in China. For the fourth phase in the late 1990s and the early $21^{st}$ century, the emphasis was on decreasing regional disparities and income inequalities in China. It should be noted that most of these phased reforms are highly related to infrastructure investments in China.

Prior to economic reform, China's economic development strategy was mainly characterized by its emphasis on self-reliance and isolation from most of the other countries in the world. The central government of China, which controlled all kinds of budgetary allocations and investment decisions, allocated a majority of capital investments to industrial production and heavy industry development. In contrast, the infrastructure sector was put in a minor position in the general development strategy and received a fairly low priority when allocating funds among different sectors. Because of this kind of strong bias against the infrastructure sector, China's public infrastructure development was very slow for a long time prior to the economic reform in 1979. The new development strategy of "reform and opening-up" initiated in 1979 provides a historical opportunity for infrastructure developments in China. The new strategy, which mainly focuses on developing the Chinese economy through international trade and foreign direct investment, places the infrastructure sector in a top priority compared with other sectors in China. The improvements and developments of public infrastructure are considered as one of the most critical preconditions in attracting foreign investment and

trading with the outside world. For many local governments in China, a high-level infrastructure establishment is one of the major selling points for these regions to attract external capital, technologies and skilled labors.

- **Streamlining Central-Local Fiscal and Tax Relations**

As economic reform progresses steadily in China, streamlining central-local fiscal and tax relations has been a high priority for the phased reform in China. Prior to the economic reform, the central government had direct control over local governments in terms of fiscal and tax relations. Centralized revenue collection and fiscal transfers had characterized the fiscal system of China under a highly-centralized planning economy for a long time. Specifically, all profits and taxes were collected by local governments, turned over to the central government, and then transferred back to the local governments based on their expenditure needs and budgets approved by the central government. As to the infrastructure development under this situation, the central government had the absolute authority and power to devise, budget and manage most of the infrastructure projects in China directly. The local governments had little autonomy and financial resources to determine their infrastructure development path.

This kind of centrally-planned central-local fiscal and tax relations has been greatly changed since 1979 when the economic reform began. One of the main sub-goals of the reform is to decentralize the traditional centralized fiscal and tax system and give local governments more autonomy and power for fiscal and tax management of their own. Specifically, a new fiscal contracting system was introduced and then applied for the

period of 1980-1993. Under the new system, some central fixed revenues, such as Custom's duties and so on, were collected by the central government. All other revenues (labeled as local revenues) were then shared by the central and local government based on a predetermined share formula, which was not based on a general rule but on a yearly negotiation between the central government and each local government respectively. On January 1, 1994, China introduced a new set of reform measures to further rationalize central-local fiscal and tax relations, where a clear distinction between national and local taxes were established for the first time. More importantly, since some taxes with high revenue-generation capacity were categorized as local taxes, local governments have considerable autonomy and freedom to determine how these revenues from local taxes can be used to develop their local economies. Then, under the new development strategy of "reform and opening-up", the local governments have adequate willingness and considerable capital to develop local infrastructure of their own.

- **Diversification of Mechanisms for Financing Infrastructure**

The devolution of the central-local fiscal and tax relations results in another important institutional change that has significant effects on infrastructure investment and development in China. The institutional change concerns the diversification of financing mechanisms for infrastructure at the local level in China. Actually, the introduction of local taxes for local governments has provided an important mechanism for financing local infrastructure developments in China. However, as the "reform and opening-up" strategy progresses, the pace of infrastructure development in China still cannot satisfy the requirements of rapid economic growth and development in China. More diversified

mechanisms for infrastructure financing are thus urgently needed for both central and local government. More and more infrastructure projects have been financed through both state and non-sate channels. Diversified capital channels for financing infrastructure in China include not only central and local taxes and budgetary allocations, but also financial bonds and equities, domestic loans and bank credits, enterprise self-raised funds, foreign capital and funds from private channels. More importantly, the emergence of diversified mechanisms for infrastructure financing also changed the incentive structure for China's infrastructure sector. Infrastructure projects financed from different channels are surely constructed with greater efficiency and transparency and with stricter supervision and management.

- **Great Western Development Strategy in China**

China's market-oriented economic reform has been very successful since its inception in 1979. China has been one of the fastest-growing economies in the world, with significant increases in international trade and huge inflows of Foreign Direct Investment (FDI). However, China's economic reforms also created some new challenges and problems, among which is the growing inequality in economic growth between coastal regions of eastern China and interior regions of western China. Achieving more balanced economic growth and development has been one of the urgent and paramount challenges for the Chinese government to obtain sustainable economic growth and social stability in the long run. Under this background, China's great western development strategy was formulated and implemented in 1999 to boost the economic growth in China's less

developed western regions. The west mega-region covered by the strategy[25] contains

71.4% of mainland China's area but only 28.8% of its population in 2002 with 16.8% of

its national GDP in 2003. Among the main components of the strategy, the development

of infrastructure has been considered as a precondition for the success of the whole

strategy and thus assigned a top priority. Therefore, it can be said without exaggeration

that China's great western development strategy has created an institutional environment

that is the most favorable for infrastructure development in China's less developed

western regions since the establishment of the People's Republic of China in 1949. By the

end of 2007, China has started 92 key infrastructure projects in its western regions, with a

total investment of more than 1.3 trillion Chinese Yuan[26].

## 3.4.2 Policy Stimulus behind the Rapid Growth of Infrastructure in China

Some important institutional changes behind the rapid growth of pubic infrastructure in

China have been discussed in the subsection above, where the emphasis is mainly

focused on how these institutional changes may affect the infrastructure development in

China as a whole. In this subsection, the emphasis is then focused on the two specific

infrastructure sectors of transportation and telecommunication, which are not only the

core components of infrastructure but also coincide with the narrowly-defined

infrastructure concept employed in the dissertation research. Some specific sectoral

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[25]The strategy covers 6 provinces (Gansu, Guizhou, Qinghai, Shanxi, Sichuan, and Yunnan), 5 autonomous regions (Guangxi, Inner Mongolia, Ningxia, Tibet, and Xinjiang), and 1 municipality (Chongqing).
[26] The data source is "http://rss.xinhuanet.com/newsc/english/2008-06/21/content_8413779.htm".

policies attempting to stimulate the infrastructure investment and development in the two sectors of transportation and telecommunication are addressed separately below.

- **Policy Stimulus for the Development of Transportation Infrastructure**

Since the beginning of the 1980s, the Chinese government has adopted a series of aggressive policies to stimulate the development of the transportation sector with the main purpose of enlarging channels for financing transportation infrastructure in China. In December 1982, a special fund was established by the State Council to finance infrastructure constructions in the sectors of energy and transportation. In December 1984, the "*Three-point instruction*" was stipulated by the State Council to enlarge the financing channels for highway construction and then to boost highway construction in China:

- The surcharge fee for vehicle purchase was imposed to finance highway construction on May 1, 1985.

- The fee for highway maintenance was adjusted to a higher level.

- The road toll and bridge toll were allowed to collect for those highways and bridges constructed from the financing channels of pooling of funds and bank loans.

In order to boost railway construction, a special fund for railway construction was established by the State Council on March 1, 1991. Moreover, a surcharge fee for railway construction was allowed to be collected for financing the railway construction in the

three provinces of Shandong, Sichuan and Fujian in April 1991. Some preferential policies have also been adopted to finance railway construction through bank loans and bonds.

Some policy stimuli were also applied to promote the development of aviation infrastructure in China. An airport construction fee was collected by both the central and local government to finance airport construction and expansion since March 1992. Moreover, the Civil Aviation Administration of China (CAAC) began to collect fees for the construction fund for aviation infrastructure from all domestic Airlines in China on January 1, 1993. The fund is collected in proportion to the annual gross revenue for each Airlines and is used specially to finance aviation infrastructure projects in China. Finally, the State Council also strongly supported the civil aviation department in China to issue aviation bonds publicly for funding the development of aviation infrastructure.

In terms of the development of port infrastructure in China, some policy stimuli were also implemented. In 1985, the State Council began to collect port construction fees on the goods flowing through. The scope and standard for the port construction fee were then enlarged and increased in 1993. Meanwhile, the surcharge for transporting goods in the inland waterways of China was also collected. Finally, the Transportation department in China also strongly encouraged various kinds of investors to invest in port construction and even allowed the owners of goods to build commercial docks specially for the use of their own.

● **Policy Stimulus for the Development of Telecommunications Infrastructure**

Since the beginning of China's economic reform initiated in 1979, the Chinese government has given a high priority to the telecommunications sector and has adopted a series of aggressive policies (financial stimuli in particular) to boost the development of telecommunications infrastructure in China. Since a number of researchers have provided detailed discussions on this issue (Gao and Lyytinen, 2000; Lu and Wong, 2003; Ding, 2005), these policy stimuli are briefly summarized and discussed below.

In October 1984, the State Council formulated the "*Six-point instruction*", which gave a high priority for the development of the postal and telecommunications sector in China. In particular, a "*three 90-percent*" policy was implemented to further promote the rapid development of the sector:

- The Ministry of Posts and Telecommunications (MPT) can retain 90 percent of its profit for the development of postal and telecommunications infrastructure[27].

- The Ministry of Posts and Telecommunications (MPT) can retain 90 percent of its foreign exchange earnings to develop postal and telecommunications infrastructure.

- 90 percent of the central government investment for the development of the postal and telecommunications sector was not regarded as repayable.

Moreover, the postal and telecommunications sector had enjoyed very generous revenue sharing schemes with especially favorable depreciation and tax rates during the period of

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[27]The equivalent tax rate for MPT was only 10 percent, which is well below the 55 percent tax rate for other state-owned enterprises in China.

1980s and 1990s. Another policy attempting to increase the capital for telecommunications investment was the collection of installation fees for fixed-line telephone services in China. The installation fee was so high at that time that it was approximately equal to the average annual wage for a common worker in China. However, the effect of the policy was significant since the installation fee accounted for over one half of the total revenue for the telecommunications service providers in China (Ministry of Information Industry of China, 2005).

In 1994, the State Council further reinforced its strong support for the development of the telecommunications sector by announcing the "*eight policies for telecommunications development in China*":

- Providing policy priorities and supports to the telecoms sector

- Putting the overall network and service development into a unified central planning frame

- Constructing a public telecoms network nationwide

- Deregulating the market for telecom's equipment manufacturing and licensing mobile telecom's services

- Conducting independent accounting and hierarchical administration for the Posts and Telecommunications Enterprises (PTEs) with employee rewards linked to enterprise overall performance

- Supporting the Posts and Telecommunications Enterprises (PTEs) to raise funds for infrastructure development from various channels

- Fostering network modernization and rapid development of human resources

- Importing foreign advanced technologies and equipments and fully utilizing foreign capital

Lu and Wong (2003) properly summarize these important factors behind the rapid growth and development of telecommunications infrastructure in China:

> "On the demand side, the fast-growing economy and rising income fueled the hungry demand for telecoms services. On the supply side, reforms in the state-owned telecoms industry created strong incentives for business expansion. Organizational restructuring made it more effective for a nationwide network expansion plan to be implemented. A series of preferential policies made it easier for the state-owned telecoms industry to raise funds and exercise its market power. Favorable tax rates and a huge amount of state capital injection also helped the industry to take off (p.30)."

## 3.5 Summary

The infrastructure development in China has been extraordinarily rapid with great achievements in the last three decades, which also outperformed most other lower middle income countries in the world. Although infrastructure investments in China increased rapidly from 1985 to 2007, the distribution of these investments among different regions and mega-regions in China is quite unbalanced. The undeveloped regions and mega-regions in China have received more and more infrastructure investments in recent years.

The rapid growth of public infrastructure in China can be explained from the two aspects of institutional changes and policy stimuli. Some important institutional changes conducive to infrastructure development in China include reform and the opening-up strategy, streamlining central-local fiscal and tax relations, diversification of mechanisms for financing infrastructure, and China's great western development strategy. Some important policy stimuli for the rapid development of transportation and telecommunications infrastructure in China include lowered tax rates, preferential terms on bank loans and credits, and preferential policies for collecting or attracting investment funds for infrastructure constructions in China.

# 4 Literature Review

The chapter reviews the literature on the relationship between infrastructure and economic productivity. In the first section, the theoretical relationship between infrastructure and economic productivity is briefly explored. The second section reviews those empirical studies that employ the production function approach to investigate the productive effects of public infrastructure based on time series data. The third section reviews those empirical studies using the similar production function approach based on panel data. The fourth section attempts to review those empirical studies on the economic effects of infrastructure in the context of China. The final section concludes.

## 4.1 Infrastructure and Economic Productivity

Infrastructure has been demonstrated to play an important role in such economic growth and development theories as development economics, neoclassical and endogenous growth theories above in Chapter 2. When the emphasis is shifted to the relationship between infrastructure and productivity, it is not difficult to accept the assumption that public infrastructure can influence productivity. After all, the result is obvious if one can imagine an economy with factories but no utilities or trucks without roads. The importance of infrastructure to the economy has been fully demonstrated in the final report of the National Council on Public Works Improvement (1988, p.12): "The quality

of a nation's infrastructure is a critical index of its economic vitality. Reliable transportation, clean water, and safe deposit of wastes are basic elements of a civilized society and a productive economy. Their absence or failure introduces a major obstacle to growth and competitiveness".

Conceptually, several mechanisms have been proposed to demonstrate why public infrastructure may be productive. First, public infrastructure may enter into the production process as an input directly and play a direct role in promoting private sector productivity. Second, infrastructure may influence the marginal productivity of other existing factors of production, thus leading to a more productive economy as a whole. Third, infrastructure investments may lead to specialization in sectors or technologies and thus higher productivity. For example, by improving communications and increasing market size, transportation infrastructures make it possible for firms to access high-technology and high-volume production techniques, which then results in a positive and permanent impact on productivity (Chatterjee et al., 2003). Fourth, from the viewpoint of regional economics, public infrastructure may stimulate regional economy by attracting resources from other regions. Specifically, a better infrastructure environment for a region can help the region attract more inflows of skilled labors, capital and advanced technologies than those regions with less developed infrastructure. Another strong argument for this view is that infrastructure plays an important role in attracting Foreign Direct Investment (FDI) in developing countries (Mody, 1997; Sun et al., 2002).

Although the theoretical mechanisms underlying the productive effects of public infrastructure might be easily understood and accepted, there have been great controversies among numerous literatures attempting to study the impact of public infrastructure on economic productivity empirically. There are mainly four approaches that have been used to assess the productive effects of public infrastructure empirically: the production function approach, the cost function approach, the Vector Autoregressive (VAR) approach and the production frontier approach.

The production function approach extends the Cobb-Douglas production function to include the stock of public capital as an input apart from labor and private capital and then estimates the coefficients of the variables in the extended production function in log-linear form, among which the coefficient of public capital is of particular interest because it is a measure of the elasticity of output with respect to public capital and therefore measures the productivity of public capital. By assuming that private firms produce a given output at minimum cost with factor prices as exogenous and labor input and private capital as endogenous derived from the optimization of the firm's production, the cost function approach then attempts to test whether public capital can reduce private sector costs. The above two widely used approaches share one common weakness of assuming all explanatory variables (e.g., public capital stock) as exogenous, which led to the emergence of vector autoregressive (VAR) models which treat all variables as endogenous. The production frontier approach, which mainly does non-parametric analysis of the relationship between public capital and private output, also requires a fairly limited number of restrictive assumptions on the production process compared with

the traditional production function or cost function approach. By assessing the technical efficiency of a producer based on a reference production set constructed without considering any functional relationship between inputs and outputs, the production frontier approach is assumed to be able to ascertain whether public capital significantly enters into the production set with value added as output and private capital and labor as inputs.

In this Chapter, the empirical literature on the production function approach will be reviewed in great details mainly for the following two reasons. For one thing, the production function approach is the most classical approach widely applied in the empirical literature and is often selected as a benchmark against which to evaluate the results estimated from the other three approaches. For another, since one of the methodologies employed in the dissertation is directly derived and developed from the production function approach, it is necessary to survey the empirical literature on the production function approach comprehensively.

## 4.2 The Production Function Approach Based on Time Series Data

The beginning of the large body of empirical literature on the productive effects of public infrastructure is generally related to the influential work of Aschauer (1989), who proposed that public infrastructure in the United States was highly productive and a large portion of the productivity slowdown in the 1970s should be attributed to the decline in public infrastructure spending occurred during the same period. The arguments of

Aschauer (1989) are enlightened and significant. Since the U.S. economy had experienced dramatic decrease in per-capita output and labor-productivity growth rates for over one decade beginning in the early 1970s[28], a huge number of economic studies attempting to analyze the possible reasons of the U.S. productivity slowdown emerged, most of which concentrated on such factors as energy price, social regulation, the composition of the workforce, research and development, different rates of obsolescence of the private capital stock, and others with only a few considering the factor associated with public infrastructure. However, an important fact neglected by many researchers at that time is that the U.S. investment in public infrastructure also witnessed a similar sharp fall as that in per-capita output and labor-productivity growth rates, with the average growth rate of government capital falling from 4.1 percent for 1950 – 1970 to 1.6 percent for 1971 – 1985. By advocating the view that the government's stock of capital is an important factor in explaining the U.S. productivity slowdown, Aschauer (1989) examined the downward movements of infrastructure investment and aggregate productivity econometrically, which spurred a number of studies examining the relationship between public infrastructure and economic productivity in the U.S. as well as in other parts of the world.

The production function approach generally extends an aggregated Cobb-Douglas production function to include the stock of public capital[29] as an input apart from labor and private capital. This approach takes the following form:

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[28]The U.S. per-capita output and labor-productivity growth rates averaged 1.3 percent and 0.8 percent respectively for the 1970 – 1989 period compared to 2.2 percent and 2.0 percent for the 1950 – 1969 period.

[29]Infrastructure is regarded as a kind of capital to enter into the production function.

$$Q_t = A_t K_t^\alpha L_t^\beta G_t^\gamma , \quad (4.1)$$

where $Q_t$ is real aggregate private output, $A_t$ is multifactor productivity, $L_t$ is labor force of the private sector, $K_t$ is private capital stock, and $G_t$ is public capital stock. The parameters $\alpha$, $\beta$, $\gamma$ can be interpreted as elasticities of output with respect to private capital, labor and public capital. Then, the equation below can be obtained by dividing both sides of the equation above by $K_t$ and taking the natural logarithm based on the assumption of constant returns to all inputs:

$$\ln\left(\frac{Q_t}{K_t}\right) = \ln(A_t) + \beta \ln\left(\frac{L_t}{K_t}\right) + \gamma \ln\left(\frac{G_t}{K_t}\right) \quad (4.2)$$

In the pioneering study of Aschauer (1989), a constant ($a_0$) and a time trend (t) are introduced as a proxy for multifactor productivity $\ln(A_t)$. Moreover, the capacity utilization rate ($CU_t$) is also included to control for the effects of the business cycle on productivity. Then the following equation is:

$$\ln\left(\frac{Q_t}{K_t}\right) = a_0 + a_1 t + \beta \ln\left(\frac{L_t}{K_t}\right) + \gamma \ln\left(\frac{G_t}{K_t}\right) + \delta \ln(CU_t) \quad (4.3)$$

This specification is then typically used in many empirical investigations to study the economic effects of public infrastructure within the framework of the production function approach, where the estimate of the output elasticity in regard to public capital $\gamma$ is of particular interest and importance to each researcher since $\gamma$ measures the productivity of public capital.

It should be noted that the Cobb-Douglas production function approach is subject to the following two main weaknesses intrinsic in the specification of the Cobb-Douglas production function. For one thing, the definition of a Cobb-Douglas production function strictly restricts the substitution elasticities of the production factors to be a total of one. Although a translog function is a more general form of production function than the Cobb-Douglas function, the Cobb-Douglas production function is still the most widely used functional form in empirical studies. For another, the production function approach assumes that the explanatory variables of labor and capital should be exogenous, which means that it is only the production factors that can cause output but not the reverse. Of course, as no flawless model exists in the world, the two drawbacks intrinsically exist in almost any empirical studies relying on the Cobb-Douglas production function approach while at the same time these have not prevented the wide application of the Cobb-Douglas production function in academic research.

Table 7 gives a brief summary of the main production function studies on the productive effects of public capital based on time series data sets. The research relying on the two functional forms of Cobb-Douglas function and translog function are surveyed. Also, two important issues need to be clarified. First, all articles selected are published in English. Second, only empirical studies at the aggregate level are included and reviewed since this research focuses on the macroeconomic effects of public infrastructure. As can be seen from the table, the output elasticity of public capital $\gamma$ varies between 0.06 and 0.59 in those studies where $\gamma$ is found to be statistically significant though $\gamma$ is insignificant in some other published research studies. Moreover, the studies using the translog function

specification seem to give more positive results than those using the Cobb-Douglas

function specification on the productive effectiveness of public capital.

*Table 7: Summary of Studies on Productive Effects of Public Capital Using the*
*Production Function Approach on Time Series Data*

| Study | Aggregation Level | Specification | Study period | Output elasticity of public capital |
|---|---|---|---|---|
| Ratner (1983) | National (U.S.) | Cobb-Douglas; log level | 1949-1973 | 0.06 |
| Aschauer (1989) | National (U.S.) | Cobb-Douglas; log level | 1949-1985 | 0.39 |
| Ram and Ramsey (1989) | National (U.S.) | Cobb-Douglas; log level | 1949-1985 | 0.24 |
| Munnell (1990) | National (U.S.) | Cobb-Douglas; log level | 1949-1987 | 0.31-0.39 |
| Hulten and Schwab (1991a) | National (U.S.) | Cobb-Douglas; log level | 1949-1985 | 0.21 |
| Eisner (1994) | National (U.S.) | Cobb-Douglas; log level | 1961-1991 | 0.27 |
| Sturm and De Haan (1995) | National (U.S.) | Cobb-Douglas; log level | 1949-1985 | 0.41 |
| Berndt and Hansson (1991) | National (Sweden) | Cobb-Douglas; log level | 1960-1988 | mixed results |
| Bajo-Rubio and Sosvilla-Rivero (1993) | National (Spain) | Cobb-Douglas; log level | 1964-1988 | 0.19 |
| Garcia-Faontes and Serra (1994) | National (Spain) | Cobb-Douglas; log level | 1964-1988 | 0.27 |
| Argimon et al. (1994) | National (Spain) | Cobb-Douglas; log level | 1964-1989 | 0.59 |
| Gonzalez-Paramo (1995) | National (Spain) | Cobb-Douglas; log level | 1964-1988 | 0.51 |
| Otto and Voss (1994) | National (Australia) | Cobb-Douglas; log level | 1966-1990 | 0.38-0.45 |
| Tatom (1991) | National (U.S.) | Cobb-Douglas; delta log | 1949-1989 | insignificant |
| Hulten and Schwab (1991b) | National (U.S.) | Cobb-Douglas; delta log | 1949-1985 | insignificant |
| Sturm and De Haan (1995) | National (U.S.) | Cobb-Douglas; delta log | 1949-1985 | insignificant |
| Sturm and De Haan (1995) | National (Netherlands) | Cobb-Douglas; delta log | 1960-1990 | insignificant |
| Ramirez (2002) | National (Mexico) | Cobb-Douglas; delta log | 1955-1994 | 0.59 |
| Ford and Poret (1991) | National (11 OECD countries) | Cobb-Douglas; delta log | 1961-1989 | Only significant in several countries |

| Everaert (2003) | National (Belgium) | Cobb-Douglas with a single-equation cointegration analysis | 1953-1996 | 0.29 |
|---|---|---|---|---|
| Kamps (2004) | National (22 OECD countries) | Cobb-Douglas; delta log | 1960-2001 | mixed results |
| Dalamagas (1995) | National (Greece) | Translog; level | 1950-1992 | 0.53 |

The enormous empirical literature reporting on the study of the productive effects of public capital relying on the production function approach begins with the influential work of Aschauer (1989), who estimates the output elasticity with regard to public capital using the U.S. national data from 1949 to 1985 under the Cobb-Douglas production function model specified before. Aschauer's research indicates that the elasticity of output in regard to nonmilitary government capital is 0.39 for the United States from 1949 to 1985. Following the similar methodology[30] in Aschauer's study (1989), some researchers obtain a similar conclusion as Aschauer (1989) that the output elasticity regarding public capital in the U.S. is really statistically significant and positive[31] (Ram and Ramsey, 1989; Munnell, 1990; Hulten and Schwab, 1991a; Eisner, 1994; Sturm and De Haan, 1995). Moreover, a similar methodology has also been used to study the productive effects of public capital in such other countries as Spain (Bajo-Rubio and Sosvilla-Rivero, 1993; Garcia-Faontes and Serra, 1994; Argimon et al., 1994; Gonzalez-Paramo, 1995), Sweden (Berndt and Hansson, 1991), Australia (Otto and Voss, 1994), China (Ma, 2000; Lou, 2003; Fan, 2004; Zhu, 2004; Wang, 2006). All these studies also find statistically significant and positive output elasticities of public capital in different

[30]The methodologies employed by some of these researchers are not absolutely identical to that of Aschauer (1989). Ram and Ramsey (1989) include a relative energy price term in their regression model. Munnell (1990) does not include the time trend in her model.

[31]The output elasticity with respect to public capital varies from 0.21 to 0.54.

countries. However, the research conduced by Berndt and Hansson (1991) gives fairly confused results when applying the Cobb-Douglas functional forms of Aschauer (1989) and Munnell (1990) respectively to the annual Swedish data for 1964-1988. The output elasticity of public capital produced from Aschauer's specification is statistically significant but implausibly greater than unity (1.601), while the elasticity from Munnell's specification is normally positive and statistically significant (0.687). This phenomenon partially reflects a drawback of time-series regressions: non-robust and sometimes implausible parameter estimates may be yielded.

These studies in support of the productive effects of public capital relying on the aggregate Cobb-Douglas production function time series approach have been questioned and criticized by many researchers (Aaron, 1990; Schultze, 1990; Hulten and Schwab, 1991b; Rubin, 1991; Jorgenson, 1991; Tatom, 1991, 1993). These econometric problems are mainly concentrated on specification issues, reverse causation, spurious correlation and nonstationarity.

- **Specification issues**

The criticisms on the specification of Aschauer's model mainly concern two kinds of shortcomings. The first involves the missing variable issue. Tatom (1991) argues that the reported large output elasticities of public capital may be due to the ignorance of the significant influence of the relative energy price on productivity. By including the relative price of energy as an input in the Cobb-Douglas production function to form another specification, Tatom finds that the output elasticities of public capital are greatly reduced

though still positive and statistically significant. However, Tatom's approach receives criticism precisely for his mixture of production function and cost function variables (Gramlich, 1994; Duggal et al., 1999). Duggal et al. (1999) further explain that the relative energy price is actually a market cost factor and thus should be included in the firm's cost function. Therefore, both researchers suggest that the energy quantities, rather than the relative energy price, should be included in the production function.

The second shortcoming refers to the inclusion of the degree of capacity utilization for capital. As already mentioned, the main reason for the inclusion of capacity utilization rate for capital in the Cobb-Douglas production function model is based on the fact that the annual services actually provided by the private and public capital stocks are subject to change for the influence of the business cycles and may not equal the possible maximum amount of services. Since the annual data for private and public capital stocks only provide the proxy information for the maximum possible services from private and public capital for each year, some measures must be used to calculate the actual services provided by the two kinds of capital for each year. The measure undertaken by Aschauer (1989) and some other researchers (Munnell, 1990; Ford and Poret, 1991; Hulten and Schwab, 1991a; Sturm and De Haan, 1995) are to include the capacity utilization rate in manufacturing as an additional variable to capture the influence of the business cycles on private outputs. This method is also subject to critique. Tatom (1991) criticizes the method for not providing corresponding justifications and not giving answers as to whether the method is intended to "capture any influences besides the varying use of the stock of business sector capital (p.6)". Furthermore, Duggal et al. (1999) argue that the

74

approach actually regards capacity utilization as a multiplicative factor in the production function, which indeed introduces a very restrictive and unrealistic assumption to the model. However, Sturm and De Haan (1995) show that whether or not the capacity utilization is included in a specification is really not crucial for their inclusions on the productive effects of public capital.

● **Reverse causation**

Eisner (1991) and Musgrave (1990) are those who first raised the question of reverse causation. The problem arises from the fact that two different interpretations can be made as to the regression result Aschauer (1989) obtains: does the leveling off of public capital reduce the growth of output, or does the reduced growth of output reduce the demand for public capital (Eisner, 1991; Gramlich, 1994; Sturm et al., 1998)? Furthermore, the second interpretation is particularly supported by Wagner's Law that government expenditure is a superior goods, which means the demand for this good grows faster than income. Therefore, governments experiencing higher productivity growth and income level tend to invest more in governmental expenditures and public capital spending. Since each of the two possible situations can lead to the empirical results obtained by Aschauer (1989), it is really imprudent and irrational to affirm or deny any of the two possibilities without conducting any further analysis and tests.

As a matter of fact, Aschauer (1989) himself noted this problem and offered two checks to test the appropriateness of the interpretation opposite to his own. For one thing, after using a lagged value of the public capital ratio as an instrument for contemporaneous

value in two-stage least squares regression estimates, he finds that the results are not changed and still robust. For another, Aschauer (1989) isolates a particular sector and the associated certain type of public capital judged *ex ante* to have productive effect on the sector. He finds that the particular public capital does have higher productive effects on the particular sector than the total public capital does on the general private sectors as a whole. Therefore, Aschauer (1989) concludes from the results that both of the checks are against the possibility of reverse causation running from productivity to infrastructure investment.

The potential theoretical justification underlying Aschauer's first method of using lagged value of the public capital as the instrument variable is that if an increase in public capital can lead to a subsequent change in productivity growth, then it can be concluded that public capital causes productivity. Aschauer's method is enlightened and reasonable in that it introduces the idea of using values of time lag to determine the directions of causation and then makes some tests in the direction. However, Aschauer's work is incomplete to some extent. He neglects the fact that the causation between public capital and productivity may be "bidirectional", which means that the causation relationships can simultaneously exist from each side to the other. Therefore, Aschauer does not test whether an increase in productivity can lead to a subsequent change in public capital formation and cannot obtain any ideas about whether productivity causes public capital. Aschauer's method of a one-directional test is particularly problematic if the productivity values always change in one direction of either increasing or decreasing, which is exactly the main reason for Ford and Pierre (1991) to question Aschauer's first method of testing

by arguing that "the slowdown in TFP was stretched out over many years" during his research period.

Tatom (1993) conducts a series of comprehensive lead-lag tests to check whether there are causal linkages between productivity and public capital from both sides. In fact, this kind of bidirectional causations between two factors is called "Granger causality", a test which investigates whether changes in one of two variables have statistically significant relationships with past changes in the other. As Tatom (1993) pointed out, one of the most obvious advantages of "Granger causality" test is that "it explicitly examines whether lagged or past information is statistically significant important for one measure or the other (p.19)", which absolutely helps resolve the causation debate on public capital and productivity. Totam (1993) then examines the possible positive causalities[32] between public capital and productivity allowing for lagged relationships of up to several years but gets the opposite conclusion as that of Aschauer (1989), finding that there is no evidence that public capital formation promotes the growth of Total Factor Productivity (TFP) but the reverse causality relationship is supported for the U.S. period 1949 to 1990.

As to the second technique on the isolation of different sectors and different types of public capital investments, Ford and Pierre (1991) believe that it is more effective in controlling for reverse causality than the first one of instrumental variables used by Aschauer (1989) though they do not give any reason for their conclusion. In fact, Neither Aschauer (1989) nor Ford and Pierre (1991) give any theoretical justifications as to why

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[32]Causality can involve negative or positive relationships between two variables, but Totam (1993) only examines the positive relations between public capital and productivity.

the second technique can resolve the reverse causation issue. The theoretical assumption underlying the second method may be that if public capital investments do affect productivity, different types of public capital should have different productive effects on different sectors, depending on to what extent the sectors directly benefit from the public capital. Here, the question is: can the possibility of causation from public capital to productivity be affirmed and the possibility of reverse causation be rejected if the hypothesis that the particular public investments judged *ex ante* to be more important to productivity exhibiting higher output elasticities in the actual empirical analysis is proved to be valid. Moreover, the empirical works of some researchers (Fernald, 1990; Rubin, 1991) do not find that public capital necessarily correlates to productivity most in sectors that should have benefited most from the public investments, which makes this check method even more vulnerable.

● **Spurious correlation and nonstationarity**

Spurious regression is a common problem in time series regression studies, which is highly correlated with the nature of the time series data. In the standard time series regression, one of the most important assumptions is that the corresponding time series data for the dependent variable and the regressors must be stationary. According to the definition given by Stock and Watson (2002), a time series variable is stationary if its probability distribution does not change over time. Simply speaking, a stationary time series variable requires that its historical relationship can be generalized to the future or

the future is like the past. If the stationary assumption cannot be satisfied in time series regression, the results of conventional statistical tests and inferences can be unreliable. In addition, the precise problem created by nonstationarity depends on the nature of the nonstationarity. Generally speaking, there are mainly two kinds of nonstationarity in economic time series data: trends and breaks. A trend can be defined as a persistent long-term movement of a variable over time. Depending on whether the trend is a random function of time or not, trends in time series data can be divided into stochastic or deterministic trends accordingly. Stochastic trends more commonly exist in the actual time series data and can lead to such problems as spurious regression, non-normal distribution of t-statistics and so on.

The problem of spurious regression is just the one that is put forward by many researchers as the most serious econometric problem to the aggregate Cobb-Douglas production function time-series econometric models. Theoretically speaking, spurious regressions exist when stochastic trends in both dependent and independent variable lead two time series to appear to be correlated when they are not actually. As to the particular time series regression study of the relationship between public capital and productivity, many researchers (Aaron, 1990; Hulten and Schwab, 1991a; Jorgenson, 1991; Tatom, 1991, 1993; Gramlich, 1994; Sturm and Haan, 1995, 1998; Ramirez, 2002; Everaert, 2003; Kamps, 2004; Destefanis, 2005) demonstrate that the time series for the dependent variable (productivity) and the independent variables (public and private capital, labor) in

the studies of Aschauer (1989), Munnell (1990) and others are both non-stationary in nature and have the common stochastic trends in particular.

Although it has been generally accepted that most of the macro time series variables for output, public capital and others in the empirical studies of estimating the output elasticity of public capital are not stationary and the related statistical results are therefore subject spuriousness, there exist many controversies as to how to resolve the non-stationarity problem. Some researchers (Aaron, 1990; Hulten and Schwab, 1991a; Jorgenson, 1991; Tatom, 1991, 1993; Sturm and Haan, 1995) believe that the method of first-differencing is able to transform the non-stationary time series to stationary ones and to remove the common trends for the estimation of the true relationships between the two variables of output and public capital. Meanwhile, Hulten and Schwab (1991a), Totam (1991) and Sturm and Haan (1995) estimated the parameters of the aggregate Cobb-Douglas production function time-series model in a first-difference specification, each of which finds that the positive coefficient on public capital is much smaller than that in the estimation based on the level of the public capital and is no longer statistically significant. However, Hulten and Schwab (1991a) even find that private capital and labor are also insignificant besides public capital in their research. Sturm and Haan (1995) get the similar result of the insignificance of private capital and labor as well.

It cannot be denied that first differencing has its own problems. As pointed out by Everaert (2001) and Destefanis (2005), first-differencing estimation has all trend

components removed, putting great weight on high-frequency disturbances. This is nearly equivalent to assuming that the effect of public capital increase on productivity in a particular year is completely realized during the same year (Munnell, 1992). Specifically, Munnell (1992) questioned the validity of the first-differencing method by arguing that differencing could destroy any long-term relationships in the time series and could yield implausible estimations of the coefficients for public capital, labor and other independent variables which are exactly the cases in the studies of Hulten and Schwab (1991), Totam (1991) and Sturm and Haan (1995). In fact, as mentioned before, economic theory suggests that public capital affects productivity at much lower frequencies. The effects of public capital stock on productivity may even be permanent (Destefanis, 2005). This kind of low-frequency component is just removed by first differencing. Moreover, Duggal et al. (1999) argue that the fact that first differenced equations produce implausible and insignificant estimates of the output elasticities for private capital and labor as well as public capital has been sufficient for questioning the feasibility of first differencing to capture any possible long-term relationship. After all, no one doubts the contributions of private capital and labor to productivity though it is not the case for public capital.

Indeed, the concept of cointegration[33] might be much more relevant than simply first differencing in handling nonstationarity issues. Specifically, more and more researchers (Munnell, 1992; Tatom, 1991, 1993; Bajo-Rubio and Sosvilla-Rivero, 1993; Gramlich,

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[33]First, cointegration means that a linear combination of individually nonstationary series is itself stationary. Second, cointegration between two variables also means that "there must exist an error correction mechanism, with at least one of the two variables adjusting to keep the long-run equilibrium relationship intact" (Canning and Pedroni, 1999:3). Third, If variables are tested and have a unit root, then these variables are not cointegrated.

1994; Sturm and Haan 1995; Ramirez, 2002; Everaert, 2003; Kamps, 2004; Destefanis, 2005) believe that researchers should not only examine the extent to which the time series variables are nonstationary, but also whether they grow together over time and converge to certain long-run relationship (i.e. whether they are cointegrated). Here, the relationship between first differencing and cointegration is briefly summarized. First, first differencing and cointegration are the two main ways to deal with nonstationary time series. Second, first differencing, which can destroy the long-term relationship between the series, is really unnecessary and inappropriate if the nonstationary series are cointegrated. More importantly, an obvious advantage of conintegration over first differencing is described as below: if the variables are cointegrated, the estimated OLS coefficients from regression of the level of nonstationary series converge in probability much faster to their true population values than in OLS regressions of stationary series[34] (Stock, 1987). This advantage is critical when only a relative small sample size is available. Third, if the variables are not cointegrated, then first differencing might be the last option to obtain stationary series.

Various researchers have followed the idea of cointegration with fairly mixed results. Lynde and Richmond (1993) provide evidence that the U.S. times series (1958-1989) under study (output, employment, private and public capital) are nonstationary but are cointegrated using the augmented Engle-Granger test. Based on the same test method, Bajo-Rubio and Sosvilla-Rivero (1993) find a clear cointegrating relationship among nonstationary time series (1964-1988) of output, employment, private and public capital

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[34]This kind of OLS estimator is said to be super-consistent.

in Spain. Hamilton (1996) includes public capital as well as human capital and R&D into the aggregate production function model in addition to labor and private capital, finding that the model is cointegrated for the US data from 1948 to 1993.

By contrast, quite a few studies get negative results on cointegration. Tatom (1991) finds no evidence of cointegration of the nonstationary time series of private output and pubic capital by using Stock and Watson's Dynamic OLS procedure (1993), which involves including significant lags and leads of first-differences of the dependent and independent variables in the equation. Sturm and de Haan (1995) test US data (1949-1985) and data for the Netherlands (1960-1990), concluding that the nonstationary series of public capital and private output are not cointegrated using the popular residual-based test proposed by Engle and Granger[35] (1987). Pereira and Flores (1995) test OECD data on the US (1956-1989), finding that the series under consideration (output, labor, private and public capital) are nonstationary but are not cointegrated using the same residual based test from Engle and Granger (1987). Pereira and Morin (1996) study time series data on output, employment, private and public capital for eleven OECD economies, showing that these nonstationary data series are not cointegrated for most of the countries except for Belgium, Canada, Germany and Spain based on the augmented Engle-Granger test. More recently, Kamps (2004) employs the same augmented Engle-Granger test, finding

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[35]Engle and Granger (1987) proposed a two-step procedure to test for cointegration: First, estimating the regression equation in levels; Second, testing the residuals from the regression using an augmented Dickey-Fuller test to determine whether it has a unit root. If the null hypothesis that the residuals have a unit root can be rejected, then the series are cointegrated.

that the time series data on output, labor, private and public capital are nonstationary and also non-cointegrated in all cases of the 22 OECD countries.

However, these studies with negative results on cointegration have been severely questioned on the following two grounds. For one thing, misspecification of the model is an issue. Everaert (2001) questions the non-cointegration conclusion from Tatom (1991) for the inclusion of energy prices in his specification of the production function. More importantly, he further points out that the inclusion of both a linear time trend to capture the technological progress and a capacity utilization rate to capture short-term disturbances in the specification of Sturm and de Haan (1995) for the augmented Engle-Granger test is completely misleading and unreasonable. Specifically, Everaert (2001, p.101) argues that "Besides the fact that within the context of cointegration, short-term disturbances are adequately captured by an error-correction model, both variables simply cannot cointegrate with multi-factor productivity for they are not integrated processes. Moreover, including time as one of the regressors implies looking for cointegration in linearly detrended data. This is clearly in contradiction to the results from the unit root tests[36] and with the notion of long-run equilibrium."

In fact, Kamps (2004) also draws the non-cointegration conclusions for all cases of the 22 OECD countries in his study based on the similar specification as that of Sturm and de Haan (1994) by including a linear time trend in the Cobb-Douglas production function

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[36]Nelson et al. (1981) find a "linearly detrended random walk is likely to exhibit spurious periodicity (p.745)".

model, which also makes his conclusion vulnerable. Of course, Kamps (2004) also admits that one reason for no cointegration in his study might be that a deterministic trend t might not be able to measure multi-factor productivity properly, but he gives no solution for solving this issue. By contrast, the work by Everaert (2001) is really enlightened and encouraging, in which he revises the traditional production function specification to use patent statistics instead of a deterministic trend as a proxy of technological progress and then finds cointegration of these nonstationary series related in Belgium for the period 1953-1996. More importantly, the estimated output elasticity regarding public capital in his study equals 0.29 and is highly significant, which is more plausible that those obtained by Aschauer (1989) and Munnell (1990).

For another, the other reason for the finding of no cointegration (i.e. the augmented Engle-Granger test fails to reject the null hypothesis of no cointegration) in those studies might come from the low power of the cointegration test[37], which is particularly problematic for small samples (Kamps, 2004; Destefanis, 2005). It is generally believed that "unit root tests and tests for co-integration have low power to discriminate between unit root and near unit root processes" (Enders, 1995: 251-254; Batina, 1998; Kamps, 2004), which is particularly severe for small samples (Campbell and Perron, 1991). As a special kind of unit root test (residual-based), cointegration (e.g. Engle-Granger test) test is naturally subject to the same weaknesses as those traditional unit root tests. Since the sample periods for most empirical studies on the productive effects of public capital are

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[37]Low power of the augmented Engle-Granger test for cointegration means that there is a high probability that the test cannot reject the null hypothesis of a unit root in the residual from the regression equation estimated in levels even if the series are actually cointegrated.

only several decades, many researchers believe that "one way to increase the power of unit root tests and tests for co-integration is to make use of the cross-section dimension of the data in addition to the time-series dimension" (Kamps, 2004: 45). Moreover, one notable advantage of panel data sets over conventional cross-sectional or time-series data sets is that the multicollinearity among the regressors is reduced (Hsiao, 2003). In fact, a reason why the estimated output elasticity of private capital is statistically insignificant or even negative in some studies using the production function time series approach might be due to multicollinearity. Fortunately, however, more and more researchers have used recent-developed panel data models to study the relationship between output and public capital within the framework of production function models, which is reviewed next.

## 4.3 The Production Function Approach Based on Panel Data

The studies on the productive effects of public capital based on the production function approach using panel data set (pooled time series, cross section data set) began in the early 1990s. The use of such data has two important advantages over the time series data. First, some implicit assumptions related to the time series data for a single country, such as equal marginal productivity in all its sub-national regions such states, uniform rate of technological progress over states (Aaron, 1990), can be circumvented or relaxed. Second, the cross-section variability as well as variability over time in data greatly improves the statistical properties of the test (Krol, 2001).

The table 8 below gives a brief summary of the main production function studies on the productive effects of public capital based on panel data sets. The research relying on the two functional forms of Cobb-Douglas function and translog function are surveyed. Still, two important issues need to be clarified here. First, all articles selected are published in English. Second, only empirical studies at the aggregate level are included and reviewed since this research focuses on the macroeconomic effects of public infrastructure. From the table, it seems that estimations for the output elasticity of public capital under the framework of Cobb-Douglas production function model is pretty mixed, highly correlated with the specific model specification employed by each researcher. By contrast, studies using a translog production function specification gives statistically significant results, with the output elasticities of public capital ranging from -0.11 to 0.53.

*Table 8: Summary of Studies on Productive Effects of Public Capital Using the Production Function Approach Based on Panel Data*

| Study | Aggregation Level | Specification | Study period | Output elasticity of public capital |
|---|---|---|---|---|
| Aschauer (1990) | 50 states (U.S.) | Cobb-Douglas; log level | Cross-section averaged 1965-1983 | 0.055-0.11 |
| Munnell and Cook (1990) | 48 states (U.S.) | Cobb-Douglas; log level | Pooled OLS 1970-1986 | 0.15 |
| Eisner (1991) | 48 states (U.S.) | Cobb-Douglas; log level | Pooled OLS 1970-86 | 0.17 |
| Garcia-Mil`a and McGuire (1992) | 48 states (U.S.) | Cobb-Douglas; log level | Pooled OLS 1969-1982 | 0.04-0.05 |
| Munnell (1993) | 48 states (U.S.) | Cobb-Douglas; log level | Pooled OLS 1970-1986 | 0.14-0.17 |
| Aschauer (1989b) | G-7 | Cobb-Douglas; delta log | Pooled OLS 1966-1985 | 0.34-0.73 |
| Holtz-Eakin | 48 states and 9 | Cobb-Douglas with fixed | 1969-1986 | insignificant |

| | | | | |
|---|---|---|---|---|
| (1994) | regions (U.S.) | state effects included; log level | | |
| Evans and Karras (1994a) | 48 states (U.S.) | Cobb-Douglas with fixed state effects included; log level | 1970-1986 | insignificant |
| Krol (1995) | 48 states (U.S.) | Cobb-Douglas with fixed state effects included; log level | 1970-1986 | significant negative |
| Mas et al. (1996) | 17 regions (Spain) | Cobb-Douglas with fixed state effects included; log level | 1980-1989 | 0.07 |
| Picci (1999) | 20 regions (Italy) | Cobb-Douglas with fixed and random effects included; log level | 1970-1995 | 0.36 |
| Holtz-Eakin and Schwartz (1995) | 48 states (U.S.) | Cobb-Douglas with fixed state effects included; delta log | 1970-1986 | insignificant |
| Garcia-Mil`a et al. (1996) | 48 states (U.S.) | Cobb-Douglas with fixed state effects included; delta log | 1970-1983 | insignificant |
| Evans and Karras (1994b) | 7 OECD countries | Cobb-Douglas with unobserved effects included; delta log | 1963-1988 | estimates are fragile and not significant |
| Nourzad and Vrieze (1995) | 7 OECD countries | Cobb-Douglas with unobserved effects included; delta log | 1963-1988 | 0.055 |
| Nourzad (2000) | 12 developing and 12 OECD economies | Cobb-Douglas with unobserved effects included; delta log | 1976-1989 | 0.397-0.553 |
| Kamps (2004) | National (22 OECD countries) | Cobb-Douglas; nonstationary panel model | 1960-2001 | 0.31 |
| Okubo (2008) | 46 prefectures (Japan) | Cobb-Douglas; nonstationary panel model | 1975-1999 | 0.06 |
| Pinnoi (1994) | 48 states (U.S.) | Translog; level | 1970-1986 | -0.11-0.08 |
| Eberts (1986) | 38 metropolitan areas (U.S.) | Translog; level | 1958-1978 | 0.03-0.04 |
| Merriman (1990) | 9 regions (Japan) | Translog; level | 1954-1963 | 0.43-0.58 |

Generally speaking, most of the early studies based on panel data sets mainly concern

estimates of regional-wide production functions by using pooled time series, cross section

data across states in the US (Aschauer, 1990; Munnell and Cook, 1990; Eisner, 1991; Garcia-Mil`a and McGuire, 1992; Munnell, 1993). The output elasticities regarding public capital from these state-level studies are always statistically significant and range from 0.04 to 0.17, which are for the most part lower than those from national-level studies. Munnell (1992, p.193-194) attributes this to some possible spillover effects by arguing that "because of leakages, one cannot capture the entire payoff to an infrastructure investment by looking at a small geographic area."

Although these early empirical studies favor positive effects of public capital on output, the main estimation technique employed produces great controversy. Specifically, the state (regional) production functions are estimated with Ordinary Least Squares (OLS) without consideration of state-specific effects, which refer to differential productivity across states results from location, climate, endowments and myriad other factors. Holtz-Eakin (1994) maintains that the state-specific effects and public capital are positively correlated for the main reason that more prosperous states are inclined to spend more on public capital. It is just this kind of positive correlation that produces biased and inconsistent estimates of regional-wide production functions (Holtz-Eakin, 1994; Sturm et al., 1998; Krol, 2001).

Different methods exist to control for the state-specific effects in the Cobb-Douglas production functions. The most common are the fixed-effects model and the random-effects model. The fixed-effects model estimates the production function using Ordinary

Least Squares (OLS) with inclusion of a separate dummy variable for each state to control for state-specific effects. By contrast, the random-effects model treats the state-specific effect for each state as a separate random variable and also as a component of the error term that contributes to its overall variance. Then the Generalized Least Squares (GLS) is used to estimate the production function equation.

Some researchers just employ the Cobb-Douglas production function model (all variables are in levels) to study the effects of public capital on state or regional output with consideration of fixed or random state-specific effects (Holtz-Eakin, 1994; Evans and Karras, 1994a; Krol, 1995; Mas et al., 1996; Picci, 1999). Holtz-Eakin (1994) estimates the state Cobb- Douglas production function for the U.S. during 1969 through 1986 while controlling for both unobserved state-specific effects and time effects, but finds small, insignificant and sometimes negative output elasticities regarding public capital. Only when the state production function is estimated by Ordinary Least Squares (OLS) in levels that ignores such controls, can the substantial impacts of public capital on state output be found. Evans and Karras (1994a) estimate state Cobb- Douglas production function using the same panel data set for the US from 1970 to 1986 as Munnell (1993), but control for the state-specific effects across states. Their study does not yield a statistically significant positive estimate of output elasticity regarding public capital. However, Evans and Karras's results are questionable and even spurious for the multicollinearity between independent variables because they include various measures of public investment as independent variables, which are easily correlated with one

another and public capital (Krol, 1995). Krol (1995) remedies the multicollinearity flaw in Evans and Karras's work and estimates the Cobb-Douglas production function, controlling for state-specific effects and still using the panel data set of Munnell (1993). Krol's study shows that public capital appears to have a statistically significant negative effect on gross state product.

The studies discussed above, which find insignificant or even negative impacts of public capital on state output with consideration of fixed or random state-specific effects, aim at the US economy. Nevertheless, studies using the similar panel data techniques on other countries reveal more optimistic results. Mas et al. (1996) finds a significant positive output elasticity regarding public capital of 0.07, when analyzing the impacts of public capital on the private productivity in Spain's regions from 1964 to 1991 while controlling for unobserved state-specific differences under the framework of the Cobb-Douglas production function model. Picci (1999) estimates the Cobb-Douglas production function for the 20 Italian regions with controlling for fixed and random region-specific differences over the period 1970-1995. Contrary to those similar literatures aiming at the US, Picci's estimate of output elasticity of public capital is found to be significantly positive (0.36) for the whole country when the unobserved regional effects are considered.

In fact, these studies based on state production function models with state-specific effects are not without problems. For one thing, multicollinearity is a potential problem. Ai and

Cassou (1995) analyze the data sets used by Holtz-Eakin (1994) and Evans and Karras (1994a) who estimate production models with fixed effects. Their study shows that public capital series are highly correlated with the state and time dummies, which can lead to such undesirable results as poor parameter estimates and large standard errors. Therefore, they maintain that caution must be taken when interpreting results from these studies that public capital is not productive. For another, the nonstationary nature of the panel data is still a problem since production functions are estimated in levels in these studies. Just as the problem from nonstationary time series data, regression results may also be spurious in the presence of nonstationary panel data. Although the nonstationarity issue is not raised and tested in these early studies, many researchers find that the variables of output, public capital, private capital and labor in their panel data sets are nonstationary (Evans and Karras, 1994b; Nourzad and Vrieze, 1995, 2000; Garcia-Mil`a et al., 1996; Stephan, 2003; Kamps, 2004; Destefanis and Sena, 2005; Okubo, 2008).

The first response to the nonstationarity problem in panel data sets is to first-difference the series (Garcia-Mil`a et al., 1996; Evans and Karras, 1994b; Nourzad and Vrieze, 1995; Nourzad, 2000). Garcia-Mil`a et al. (1996) use a panel data set for the US from 1970 to 1983 to estimate the Cobb-Douglas production function in first-differences with fixed state effects where public capital is included as an additional input. Their study yields no significant estimate for the output elasticity of public capital. Studies using panel data of countries find mixed results. Evans and Karras (1994b) estimate Cobb-Douglas production function in first-differences when allowing for fixed or random

92

effects to investigate how productive public capital is based on an anual panel data for seven OECD countries[38] from 1963 to 1988. Their research does not find any statistically significant evidence that public capital is productive. Nourzad (2000) uses an aggregate Cobb-Douglas production function with first-differences with control for country-specific or time-specific effects to examine the effect of public capital on productivity in an annual panel of twelve OECD and twelve developing countries[39] from 1976 to 1989. His study shows that public capital does have a significant and positive effect on output with output elasticity of public capital ranging from 0.397 to 0.553, which also holds in separate samples for both developed and developing countries. Nourzad and Vrieze (1995) also find a positive effect of public capital on private output using an annual panel data of seven OECD countries[40] over the period of 1963-1988.

Actually, estimation in first-differences is not a good solution to handle nonstationary panel data, especially when the nonstationary series are cointegrated. Specifically, when dealing with nonstationary cointegrated panel data, estimation with first-differences can also destroy any long-term relationships in the panel data series and even yield implausible estimations of coefficients, just as it does in the cointegrated nonstationary time series data. Over the past decade, more and more literature has emerged and shows that various new methods for the analysis of nonstationary panel data models have been

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[38]The seven OECD countries in this study include Belgium, Canada, Finland, Germany, Greece, the United Kingdom and the United States.

[39]The twelve developed countries include Belgium, Canada, Finland, France, Germany, Italy, Japan, Luxembourg, Spain, Sweden, the United Kingdom and the United States; The twelve developing countries include Chile, Costa Rica, El Salvador, Guatemala, Jordan, Kenya, Pakistan, Singapore, South Korea, Thailand, Turkey, and Zimbabwe.

[40]The seven OECD countries in this study include Canada, Finland, France, Germany, Sweden, the United Kingdom and the United States.

developed. Compared to the traditional nonstationary time-series analysis, the nonstationary panel analysis has the following attractive advantage that many test statistics and estimators calculated from non-stationary panel data have normal limiting distributions in contrast to pure time series analysis (Baltagi, 2005). Therefore, panel unit root tests and cointegration tests are generally more reliable and consistent than corresponding time series unit root tests and cointegration tests.

Up to now, econometric methods for non-stationary panel models have been rarely used in the analysis of productive effects of public capital, especially in the estimation of the output elasticity regarding public capital, although they have been extensively used to test purchasing power parity (Pedroni 2001) and growth convergence (Lee et al. 1997). Studies conducted by Kamps (2004) and Okubo (2008) are exceptions. Kamps (2004) attempts to estimate the elasticity of output with respect to public capital for a panel of 22 OECD countries during the period of 1970 to 2001. He first performs some panel unit root tests to determine whether the variables in the study are nonstationary. After obtaining affirmative test results on the nonstationarity of the variables, he further conducts several panel cointegration tests to investigate whether the variables are cointegrated. Since he finds the nonstationary variables to be really cointegrated, he finally gets the panel estimates of cointegration vector based on Pedroni's (2000) group-mean panel fully modified OLS estimator with the elasticities of output with respect to labor, private capital and public capital being 0.72, 0.27 and 0.31 respectively, all of which are significant at the 1 percent level. Of course, Kamps's work is not without

94

question. One of the most important weaknesses is the assumption of the panel unit root tests he uses, which assumes cross-sectional independence among the countries in the panel. The assumption is obviously restricted and unrealistic since it is really common for macro time series to exhibit significant cross-sectional correlation among the countries in the panel, which also might be popular in the regional-level panel data studies.

Okubo (2008) uses the Cobb-Douglas production function while controlling for both a fixed-effect and a common time-effect to estimate the output elasticity of public capital for the 46 prefectures of Japan from 1975 to 1999 using the panel cointegration approach of panel Dynamic Ordinary Least Squares (DOLS) proposed by Mark and Sul (2003). His study yields significant and positive estimates of output elasticity regarding public capital with values ranging from 0.06 to 0.108. Okubo's work (2008) suffers from two severe weaknesses. First, cross section dependence is not clearly recognized and handled in his panel unit root tests. Second, Okubo does not conduct any panel cointegration tests to investigate whether the variables under consideration are cointegrated before making estimations of the cointegration vector.

## 4.4 Studies on the Economic Effects of Infrastructure in China

Since its market-oriented economic reform and opening up in 1978, China has been among the countries experiencing the fastest economic growth and development in the world[41]. During the past few years, a growing body of literature has focused on China's

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[41]During the past twenty years, the average growth rate of GDP per capita is 8.4% and the total economic quantities increased by 490% in China.

economic growth and development, while the question of economic effects of public capital or infrastructure in China has rarely been raised and less studied. Actually, the states of China and the transition of Chinese government spending policies in the past two decades provide an excellent and unique opportunity to empirically study the economic effects of public capital or infrastructure, which will surely become an important and indispensable complement to the current literature on this issue.

It has been generally recognized that investment in public infrastructure can "improve the productivity of all inputs in the production process and thus strengthen long-term growth performance by facilitating market transactions and the emergence of externalities among firms or industries" (Demurger 2000: 103). In the case of China, the states and economic development strategies of China addressed below determine the fact that the public infrastructure in China should theoretically play a more important role on Chinese productivity and economic growth than most of the other countries in the world. For one thing, the Chinese territory is large and "the technological progress in China is mainly imported rather than created by local R&D activities" (Demurger 2000: 103). Therefore, the more the infrastructure facilities are developed, the easier it will be for the Chinese entrepreneurs to obtain and adopt the imported new technologies to increase productivity and economic growth. For another, one important feature of the industrial layout in China is that industrial activities are mostly concentrated on coastal regions, which are always far from those important industrial raw materials and energy resources. Therefore, the more the inter-regional infrastructure networks are developed, the more the transportation

costs are reduced, the more the cost advantages are attained and the faster the productivity and economic growth are retained.

During the past two decades, the Chinese public spending policies have experienced radical transition from planning-oriented to market-oriented. During the process of reform and opening, although the ratio of government investments to total social investments has declined consistently, Chinese government investments have gradually concentrated on public infrastructures. By the 1990s, government investment spending has almost exited from the general competitive sectors of productivity and almost completely concentrated on such public infrastructures as transportation, telecommunication, public utilities and others. The definition and scope of Chinese government spending have gradually coincided with those of most other countries in the world. By the end of the 1990s, the problem of the bottleneck caused by the inadequate public infrastructure investments and insufficient public capital stock in China on Chinese economic productivity and growth has been resolved to a great degree by government's persistent investments on public infrastructure. Undoubtedly, the whole world has witnessed the significant improvements and achievements in Chinese infrastructure endowments during the past twenty years. Moreover, the government investment policies for infrastructures have also been adapted to expand the domestic demand, regulate and control business cycles, and ultimately stimulate long-term economic growth. Finally, the Chinese government also regards the investment policies for infrastructures as an important policy tool to achieve balanced economic growth and

development across regions and provinces in China with a strong emphasis on the state's west development strategy.

Although the states of China and the transition of Chinese government spending policies and economic development strategy in the past twenty years have undoubtedly justified the complete necessity and feasibility of studying economic effects of public capital and infrastructure in China, the existing studies on this issue are fairly limited and far from satisfying. Table 9 below gives a brief summary of the main studies on the productive effects of public capital in the context of China.

*Table 9: Summary of Studies on Productive Effects of Public Capital Using the Production Function Approach in the China Context*

| Study | Aggregation Level | Specification | Study period | Output elasticity of public capital |
|---|---|---|---|---|
| Ma (2000) | National | Cobb-Douglas; log level | 1981-1998 | 0.55 |
| Lou (2003) | National | Cobb-Douglas; log level | 1978-1998 | 0.24 |
| Fan et al. (2004) | National | Cobb-Douglas; log level | 1981-2001 | 0.70 |
| Zhu (2004) | National | Cobb-Douglas; log level | 1985-2002 | 0.12 |
| Wang (2006) | National | Cobb-Douglas; log level | 1981-2000 | 0.29 |
| Gao (2005) | 28 regions | Cobb-Douglas with fixed and random effects included; log level | 1996-2003 | 0.09 |

Among those empirical studies, most of them use the similar aggregate Cobb-Douglas production function time-series model as proposed by Aschauer (1989) to estimate the output elasticities of public capital in China, finding that the estimated output elasticities of public capital are all statistically significant and positive, ranging from 0.12 to 0.70 (Ma, 2000; Lou, 2003; Fan et al., 2004; Zhu, 2004; Wang, 2006). Meanwhile, the time periods for these studies are within the last two decades since 1978 when the reform and opening policies in china were initiated. Moreover, the public infrastructure capital stocks in these studies are generally estimated by state investments in fixed assets in such sectors as transportation, postal and telecommunication services, electric power, gas and water production and supply. Since there are no official pubic capital or infrastructure stocks data available in China, this kind of estimation by certain sectors are reasonable. Finally, it should be noted that all the existing studies are still subject to such econometric problems as specification issues, reverse causation, spurious correlation and nonstationarity discussed before.

Compared with the above studies based on time series data, fewer studies estimate the output elasticity of public capital based on panel data with the exception of the work by Gao (2005). Gao estimates the Cobb-Douglas production function in levels for the 28 provinces and autonomous regions in China while controlling for fixed and random region-specific differences over the period 1996-2003. Gao's estimate of output elasticity for the core public capital in this study is found to be significantly positive (0.09) for the whole country when fixed regional effects are considered. However, Gao's study is not

without problems. First, multicollinearity is still a potential problem, which is especially severe when core public capital and non-core public capital are both included as independent variables simultaneously. Second, nonstationarity of these panel data series may produce spurious and unreliable regression results. Actually, the nonstationarity issue is not even mentioned or discussed.

## 4.5 Summary

Although it has been generally accepted that public infrastructure can influence economic productivity through a variety of mechanisms, there have been great controversies in the existing literature attempting to measure the productive effects of public infrastructure empirically. The production function approach, which estimates the output elasticity of public capital in an extended Cobb-Douglas production function with the inclusion of public capital, is one of the most widely used methods in the field. The studies using the production function approach generally give mixed results on the productive effects of public capital.

When the production function approach is employed in the context of time series data, it is generally subject to such econometric problems as specification issues, reverse causation, spurious correlation and nonstationarity. When the approach is employed in the context of panel data, some econometric problems intrinsic in the context of time series data (i.e., the nonstationarity issue) can be remedied to some extent. In particular, some researchers, who employ the newly-developed nonstationary panel techniques to estimate the output elasticity of public capital within the framework of the Cobb- Douglas

production function, find positive effects of public capital on economic productivity. However, these studies are still subject to some weaknesses and can be improved upon in a variety of aspects.

Studies on the economic effects of infrastructure in China are only in a nascent stage of development. Although most of these studies provide evidence in support of the positive effects of infrastructure on productivity in China, they still suffer some important weaknesses commonly existing in similar kinds of research. The newly-developed nonstationary panel techniques are seldom used to study the productive effects of public capital in China.

# 5 Methodologies and Data

The chapter discusses some important issues on methodologies and data in the research. The first section introduces a three-step nonstationary panel analytical procedure to investigate the productive and spillover effects of public infrastructure. The second section introduces a panel Granger causality test to study the relationship between infrastructure and productivity. The third section develops procedure for the estimation of infrastructure stocks for China from 1987 to 2003. The fourth section discusses variable measurement and data sources for the research. The final section concludes.

## 5.1 Infrastructure and Productivity: A Nonstationary Panel Analysis

As discussed in the previous Chapter, the Cobb-Douglas production function approach has been widely used to study the relationship between public infrastructure and productivity by empirically estimating the elasticity of output regarding public capital. Although this method is subject to several problems and criticisms, it is still the one most widely employed in empirical studies and also taken as a benchmark against which to evaluate the results from other methods in this field. Therefore, this tradition is followed in this dissertation for the study of the relationship between infrastructure and productivity, but is conducted in the framework of a nonstationary panel analysis.

Using panel data to assess the productive effects of public capital from the estimation of the Cobb-Douglas production function in log-linear form is far from a new approach, but few studies have attempted to undertake such work using a nonstationary panel analysis approach, except for those conducted by Kamps (2004) and Okubo (2008). Following their main specifications, the region-level aggregate Cobb-Douglas production function that includes private capital, public capital and labor as three inputs is constructed for use in analyzing the China case. Taking the natural logarithm yields the following basic regression equation typically employed in this dissertation:

$$\ln(Y_{it}) = \alpha \ln(K_{it}) + \beta \ln(L_{it}) + \gamma \ln(G_{it}) + \mu_i + \varepsilon_{it}, i = 1, \ldots, N, t = 1, \ldots, T, \quad (5.1)$$

where i and t index regions and years, N is the number of regions and T is the number of years. $Y_{it}$ is gross provincial output, $K_{it}$ is private capital, $G_{it}$ is public capital, $L_{it}$ is labor input, $\mu_i$ denotes the region-specific fixed effect for region i, and $\varepsilon_{it}$ is a disturbance error term. The parameters α, β, γ can be interpreted as output elasticities of labor, private capital and public capital. The size and significance of γ are particularly important to the research. Moreover, an assumption of constant returns to scale is not imposed although the marginal returns of factor inputs are assumed to be diminishing (0<α, β, γ<1).

Moreover, since the dissertation is about a multiplicity of regions, it is really an issue if no interregional effects are considered. Therefore, the techniques in spatial econometrics are used to test for the spatial spillover effects of public capital on regional outputs. Specifically, a spatial spillover variable, which can measure the spatial spillovers of public capital, is added to the original equation (5.1). To construct a spillovers variable, a

weight matrix, which may include first order neighbor weight matrix, distance decay weight matrix, and population-distance gravity weight matrix, must be determined first. After careful considerations, the first order neighbor weight matrix is used to construct the spillovers variable in the dissertation for the following two main reasons. For one thing, the study aims to test the existence of spillover effects of public capital among Chinese regions rather than measuring the exact amount of such spillover effects. For another, geographic distance or proximity is really a plausible method to construct the spatial weight matrix considering the variabilities in geographic accessibility and other productive endowments among Chinese regions. The new log-linear Cobb-Douglas model besides equation (5.1) is specified as below:

$$\ln(Y_{it}) = \alpha \ln(K_{it}) + \beta \ln(L_{it}) + \gamma \ln(G_{it}) + \lambda \ln(S_{it}) + \mu_i + \varepsilon_{it}, i = 1, .., N, t = 1, .., T, \quad (5.2)$$

where i and t index regions and years, N is the number of regions and T is the number of years. The new variable S is a spillover variable, which is the average of the public capitals for a region's first-order neighboring regions (i.e., S = W×G, where the spatial weight matrix W is constructed based on the first-order contiguity relations for each region). The size and significance of λ are also important since it measures whether the spillover effects of public capital exist or not among Chinese regions.

From the literature review in the previous Chapter, it has been demonstrated that the potential nonstationarity of the variables in the panel data sets may make the results from using standard regressions spurious and unreliable. Therefore, applying a nonstationary panel analysis to study the productive effects of public capital as well as the spillover

effects of public capital is a direct response to such problems as spurious correlation and nonstationarity brought about when the traditional time series and panel approaches are deployed. Although the focus of the research is to estimate the output elasticity regarding public capital using a production function, a complete nonstationary panel analysis actually includes the following three logically consistent procedures. First, it is necessary to conduct panel unit root tests to determine whether the variables are nonstationary. Second, it is necessary to undertake some panel cointegration tests to investigate whether the variables are cointegrated. Third, the final step is to estimate the panel cointegration model for the estimated output elasticities of labor, private and public capital. The specifics for each procedure are addressed in the following three sub-sections.

## 5.1.1 Panel Unit Root Tests

In the last decade, many panel unit root tests have been developed, with the main purpose to combine information from both the time-series dimension and cross-sectional dimension so that inferences about the existence of unit roots and cointegration in a time series context can be made more reliable and precise in a panel context. Since surveys of panel unit root tests have been given by many researchers (Banerjee, 1999; Choi, 2002; Breitung and Pesaran, 2005; Gutierrez, 2006; Jang and Shin, 2005), only a brief review is given below, with the main purpose of introducing the tests used in the dissertation.

For a panel data set, assume that the time series for N cross sections follow a AR(1) process:

$$y_{it} = \mu_i + \delta_i y_{i,t-1} + \varepsilon_{it}, \quad (5.3)$$

where i=1,..., N is the cross-sectional dimension of the data and t=1,..., T is the time dimension of the data. $\mu_i$ denotes a fixed effect and $\delta_i$ is an autoregressive coefficient for cross section i. In particular, the classical panel unit root tests or panel unit root tests of the first generation assume that $\varepsilon_{it}$ is an independent and identically distributed (i.i.d.) error term across i and t with $E(\varepsilon_{it})=0$, $E(\varepsilon^2_{it})=\sigma^2_i$. Actually, the relaxation of the cross section dependence assumption to cross section dependence leads to the panel unit tests of the second generation. Finally, the dependent variable $Y_{it}$ contains a unit root or a stochastic trend if $|\delta_i|=1$.

Different from unit root tests in univariate time series, the autoregressive coefficient $\delta_i$ in equation (5.3) can be the same across all cross sections ($\delta_i = \delta$) or different, which then distinguishes two types of tests in the panel unit root tests of the first generation[42]. Tests in Levin et al. (2002), Breitung (2000), Hardi (2000) consider the former homogeneous assumption, while tests in Im, Pesaran and Shin (2003), Maddala and Wu (1999) and Choi (2001) rely on the latter heterogeneous assumption. Actually, the assumption of invariance of autoregressive parameters across individual series means that the stationarity of all the series is the only alternative to a common unit root. This constitutes a restriction for the dissertation because provincial output, labor, private capital stock and public capital stock are unbalanced across individual regions in China. The tests based on the assumption of heterogeneous individual autoregressive coefficients across all cross sections do allow one to test the null hypothesis of a unit root in all series against the

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[42]All panel unit root tests of the second generation are based on the heterogeneous assumption.

heterogeneous alternative hypothesis of unit roots in some (not necessarily all) of the series. Thus tests that assume heterogeneous individual autoregressive coefficients are under consideration for the study.

Specifically, the tests of Im, Pesaran and Shin (2003), Maddala and Wu (1999) and Choi (2001) that consider heterogeneous individual autoregressive coefficients take the following Augmented Dickey Fuller test[43] (ADF henceforth) as a standard specification:

$$\Delta y_{it} = \mu_i + \omega_i t + \rho_i y_{i,t-1} + \sum_{j=1}^{q_i} \lambda_{ij} \Delta y_{i,t-j} + \varepsilon_{it} \qquad (5.4)$$

where i=1,..., N and t=1,..., T. y is the variable under consideration, $\Delta$ is the backward difference operator, $\omega_i t$ is an individual linear time trend (i.e., represents a possible deterministic trend). The coefficient $\rho_i$ is equivalent to ($\delta_i$-1) in equation (5.3), $\varepsilon_{it}$ is a random error term, and the lag order $q_i$ (the number of augmenting lagged dependent variables) may vary with different cross- sections. For the panel unit root test, the null hypothesis ($H_0$) that each individual time series in the panel contains a unit root and the alternative hypothesis ($H_1$) that at least one individual time series in the panel is stationary can be expressed as:

$$H_0: \rho_i = \rho = 0 \text{ for all } i = 1,..., N \quad (5.5)$$

$$H_1: \rho_i = 0 \text{ for } i = 1,..., N_1(N_1 \geqslant 1); \rho_i < 0 \text{ for } i = N_1 + 1, N_1 + 2,..., N. \quad (5.6)$$

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[43]Detailed information on the test is found in Chapter 17, Hamilton (1994).

For example, Im, Pesaran and Shin (2003) calculate the t-statistics for the $\rho_i$'s in the individual ADF regressions for each i (denoted as $t_{iT}(q_i)$) and then average them:

$$t_{NT}^{-} = \frac{\sum_{i=1}^{N} t_{iT}(q_i)}{N}. \quad (5.7)$$

Then the statistic that is asymptotically normal distributed for the general case with some non-zero $q_i$'s for some cross sections is given as:

$$W_{t_{NT}^{-}} = \frac{\sqrt{N}(t_{NT}^{-} - N^{-1}\sum_{i=1}^{N} E[t_{iT}(q_i)])}{\sqrt{N^{-1}\sum_{i=1}^{N} Var[t_{iT}(q_i)]}} \Rightarrow N(0,1). \quad (5.8)$$

It should be noted that $E[t_{iT}(q_i)]$ and $Var[t_{iT}(q_i)]$ are provided for several combinations of T and $q_i$ by Im, Pesaran and Shin (2003). Moreover, the deterministic components and the number of lags for each individual ADF regression must be specified to calculate the statistic.

However, as mentioned before, these classical tests of Im, Pesaran and Shin (2003), Maddala and Wu (1999) and Choi (2001) assume no cross-section dependence in the panel data, which means that the residuals $\varepsilon_{it}$ in equation (5.4) are not correlated among cross-sectional units. This is another very strict restriction. Both Banerjee et al. (2005) and Kappler (2006) argue that classical panel root tests suffer from serious size distortions if cross section dependence exists in the panel. In particular, Pesaran (2007) shows that the violation of the cross-section independence assumption usually leads to

undesirable finite sample properties of the test proposed by Im, Pesaran and Shin (2003). As to the specific research topic in this dissertation, it is natural to believe that the provincial output, labor, private capital stock and public capital stock are very likely to be correlated across individual regions in China, which is particularly significant among those regions geographically nearby or spatially contiguous. Therefore, a general diagnostic test for cross section dependence in panels proposed by Pesaran (2004) that has the correct size and sufficient power even in small samples is used to check whether cross-section dependence exists in the panel data. The test statistic for cross section dependence for a balanced panel is computed as:

$$CD = \sqrt{\frac{2T}{(N(N-1))}} \left( \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} Corr(\hat{\epsilon}_i, \hat{\epsilon}_j) \right) \Rightarrow N(0,1), \quad (5.9)$$

where $\hat{\epsilon}_i, i = 1,..., N$ is a (T×1) vector of estimated residuals of the ADF regressions from equation (5.4) and $Corr(\hat{\epsilon}_i, \hat{\epsilon}_j)$ (i≠j) is the pairwise correlation coefficient for the estimated residuals $\hat{\epsilon}_i$ and $\hat{\epsilon}_j$ from equation (5.4). The CD statistic is asymptotically distributed standard normal. More importantly, Pesaran (2004) demonstrates that the CD test performs well in small samples and is particularly useful in the case of panels with small T and large N, which is well suitable for the panel data in this research.

The essence of the unit root tests of the second generation is the allowance for cross section dependence among units. These tests are mainly proposed by Phillips and Sul (2003), Bai and Ng (2004), Moon and Perron (2004) and Pesaran (2005), all of which assume that cross section dependence comes from common unobserved factors.

Meanwhile, the test originated from Pesaran (2005) can be applied to unbalanced panels, while the other tests are only suitable for balanced panels. Therefore, Pesaran test is applied to the panel data in the research with a brief illustration as below.

The Pesaran test attempts to account for cross section dependence by assuming that the dependence structure is coming from one or more common unbiased factors. Specifically, Pesaran (2005) assumes that the error terms $\varepsilon_{it}$ in equation (5.4) follow a single common factor structure:

$$\varepsilon_{it} = \psi_i f_t + \xi_{it} \quad (5.10)$$

It is assumed that the common unobserved factor $f_t$ is stationary, which influences the panel data series by the individual specific factor loading $\psi_i$. By contrast, the idiosyncratic errors $\xi_{it}$ follow the same assumptions as the panel unit root tests of the first generation hold, which means that they are i.i.d. error terms across i and t with $E(\xi_{it})=0$, $E(\xi^2_{it})=\sigma^2_i$. Moreover, $\psi_i$, $f_t$ and $\xi_{it}$ are mutually independent for all cross sections i's. Then, cross-section dependence, which comes from the common unobserved factor, can be approximately calculated by the cross section mean:

$$\bar{y}_t = \frac{1}{N} \sum_{i=1}^{N} y_{it}. \quad (5.11)$$

Pesaran (2005) further proposes a panel unit root test robust to the presence of cross-section dependence in a heterogeneous panel based on a cross-sectionally augmented Dickey-Fuller regression (CADF):

$$\Delta y_{it} = \mu_i + \omega_i t + \alpha_i y_{i,t-1} + \beta \bar{y}_{t-1} + \sum_{j=1}^{q_i} \gamma_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q_i} \theta_{ij} \Delta \bar{y}_{i,t-j} + \xi_{it},$$
(5.12)

The test for the presence of a panel unit root can then be conducted based on the t-statistic for $\alpha_i$, either in an individual or a combined manner. Specifically, the first statistic is denoted as a cross-sectionally augmented Dickey-Fuller statistic ($CADF_i$), while the second uses the first statistic ($CADF_i$) to construct a cross-sectionally augmented version of the test statistic of Im, Pesaran and Shin (2003):

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i.$$
(5.13)

In particular, Pesaran (2005) demonstrates that the two tests of $CADF_i$ and CIPS have satisfactory size and power even when the values of N and T are relatively small using Monte Carlo simulations, which makes the Pesaran test particularly applicable to the Chinese provincial economic panel data. Moreover, since the asymptotic distribution of the $CADF_i$ statistics and the CIPS statistic do not follow a standard Dickey-Fuller distribution due to the presence of the lagged cross-section means and its differences, Pesaran (2005) provides critical values for both the $CADF_i$ statistics and CIPS statistic.

The last step in the panel unit root rest part is to ascertain the order of integration of the variables in the econometric model under study, which is surely a basis for the panel cointegration tests.

The concept of degree of integration of a variable was first defined by Granger (1981) in a time series context. Specifically, if a time-series variable $x_t$ can become approximately stationary by differencing it d times, the variable is called integrated of order d or I(d) (denoted as $x_t \sim$ I(d)). Weakly stationary variables are then I(0) and all nonstationary variables are at least I(1). An I(1) variable $x_t$ means: if $x_t \sim$ I(1), then $\Delta x_t \sim$ I(0). Similarly, a series is I(2) if only the second difference of the series is I(0). Furthermore, Granger (1981) gives a general simplified definition of cointegration in terms of degree of integration: if a linear combination of a set of nonstationary I(1) variables is I(0), then these variables are called cointegrated. In other words, there exists a linear combination of the set of nonstationary variables (integrated of the same order 1) that can cancel out the same stochastic trend, which means that equilibrium relationships exist among these integrated variables. Therefore, the set of integrated variables has the potential to be directly related to one another or show co-movements in the long run. Finally, it should be noted that only nonstationary variables with the same order of integration can be considered cointegrated or can be related to one another in a long run relationship (Kaufmann and Stock, 2003).

The concept of degree of integration and the related definition of cointegration are almost the same for the panel nonstationary variables except that the information from both the time and cross-section dimensions are combined and considered in the panel variables. Therefore, in order to make the panel cointegration tests feasible and necessary, the set of panel variables under investigation must not only be nonstationary, but also be of the same order of integration. However, a panel unit root test can only check whether the

112

underlying variable is stationary (does not have a unit root) or not. No information can be obtained directly on the order of integration if the variable is nonstationary. In order to get the exact order of integration for a nonstationary variable, the panel unit root test can be conducted for the variable in first-difference, second-difference, or even higher. If the null hypothesis of a unit root is rejected for the first-differenced variable, the variable is integrated of order 1 or I(1); if the null hypothesis is rejected for the second-differenced variable, the variable is integrated of order 2 or I(2). This procedure will also be conducted on the panel variables in the dissertation to check whether they are nonstationary and whether they are integrated of the same order if they are nonstationary indeed[44].

## 5.1.2 Panel Cointegration Tests

The panel cointegration tests, which attempt to check whether long-run equilibrium relationships exist among a set of nonstationary panel variables integrated of the same order, have been widely studied and developed in the last decade. Two types of tests can be divided among these existing panel cointegration tests. The first type of test, proposed by Pedroni (1999, 2004), McCoskey and Kao (1998), Kao (1999), is based on the assumption of cross-sectional independence. Since this assumption is actually restrictive and unfulfilled in applied research, the second type of test, proposed by Bai and Kao (2004), Banerjee and Carrion-i-Silvestre (2006), Gengenbach, Palm and Urbain (2006), therefore study panel cointegration with cross-sectional dependence.

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[44]It is generally believed that many macroeconomic variables are nonstationary and integrated of order 1.

The first type of panel cointegration tests mainly takes two directions. Pedroni (1999, 2004) and Kao (1999), who follow the first direction by taking the hypothesis of no cointegration as the null hypothesis, use residuals derived from the panel regression to construct the test statistics and then tabulate the corresponding distributions. Their method is essentially analogous to the time-series static regression constructed by Engle and Granger (1987). The second direction, which considers the null hypothesis of cointegration rather than no cointegration in panels, refers to the test devised by McCoskey and Kao (1998). Their test, which is also a residual-based test, extends the Lagrange Multiplier (LM) test and the Locally Best Invariant (LBI) test for a Moving Average (MA) unit root in time series (Harris and Inder, 1994; Shin, 1994) to the panels.

However, panel cointegration tests of the first type suffer from an important weakness that cross-sectional independence in panels is assumed except for common time effects, just as the panel unit root rests of the first generation do. In the presence of cross-sectional dependence, these tests are subjected to large size distortions, which are particularly worse when the dimension of the panel increases (Banerjee, Marcellino and Osbat, 2004). Gengenbach, Palm and Urbain (2006) analytically study the behaviour of several popular panel cointegration tests of the first type in the presence of the cross-sectional dependence. Their study shows that the Gaussian limiting results derived for the cross-sectional independence in panels are no longer valid.

The second type of panel cointegration tests that takes cross-sectional dependence into consideration has just emerged in recent years (Bai and Kao, 2004; Banerjee and Carrion-

i-Silvestre, 2006; Gengenbach, Palm and Urbain, 2006). Following the similar assumption that cross section dependence in panels comes from common unobserved factors for the unit root tests of the second generation, the second type of panel cointegration tests also assumes that cross-sectional dependence comes from a common factor structure. Currently, all the panel cointegration tests of the second type are based on the innovative work of Bai and Ng (2004), who have developed a new methodology that uses a common factor structure of large dimensional panels to study the nature of nonstationarity in the panel data. The two researchers refer to their testing procedures as PANIC - Panel Analysis of Nonstationarity in Idiosyncratic and Common components, which accurately summarize the essence of their work: by decomposing each panel variable into unobserved (one or more) common factors and an idiosyncratic component, the nonstationarity properties of the common and idiosyncratic terms are assessed separately without any a priori knowledge on whether the other term is stationary or integrated.

Specifically, the factor analytic model of Bai and Ng (2004) is given as:

$$X_{it} = D_{it} + \lambda_i' F_t + \varrho_{it}, \quad (5.14)$$

where i=1,..., N and t=1,..., T. $D_{it}$ is an unobserved deterministic polynomial trend function, $F_t$ is a r×1 vector of common factors, $\lambda_i$ is a vector of factor loadings[45], and $e_{it}$ is the idiosyncratic error. A factor model with N panel variables has N idiosyncratic components but only a smaller number of common factors less than N. More importantly,

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[45]The term $\lambda_i' F_t$ is called a common component.

since cross-section dependence is assumed to come from the common factor structure, the idiosyncratic components $D_{it}$ are then independent by construction. It is just this idea that leads to the emergence of the second type of panel cointegration tests that takes cross-sectional dependence into consideration. Moreover, Bai and Ng (2004, p.1128) note that "a series with a factor structure is nonstationary if one or more of the common factors are nonstationary, or the idiosyncratic error is nonstationary, or both". Based on the model above, the common and idiosyncratic components of the series $X_{it}$ can be estimated as follows[46]. First, the $X_{it}$'s are differenced or differenced and demeaned depending on whether the deterministic analysis includes an intercept or both an intercept and a trend. Second, the principle component method is applied to the transformed data, with the estimations of factor loadings, differenced common factors and idiosyncratic components. Finally, the estimates of the differenced common and idiosyncratic components are re-integrated to get estimates of the common factors and idiosyncratic components.

Based on the common factor structure model proposed by Bai and Ng (2004), several panel cointegration tests have been developed that control for the cross-sectional dependence in the panel. Bai and Kao (2004) and Banerjee and Carrion-i-Silvestre (2005) study residual-based panel tests for a single cointegration relationship with exogenous independent variables, where the error term of the cointegration equation is assumed to follow a common factor structure as proposed by Bai and Ng (2004). The panel static regression model in Banerjee and Carrion-i-Silvestre (2005) is specified as[47]:

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[46]The technical details can be found in Bai and Ng (2004).
[47]Bai and Kao (2004) use a similar model to estimate a cointegrating relationship with common factors.

$$Y_{it} = \alpha_i + \beta_i X_{it} + \mu_{it} \quad (5.15)$$

$$\mu_{it} = \gamma_i' F_t + E_{it}, \quad (5.16)$$

i=1,..., N and t=1,..., T. The error term $\mu_{it}$ follows a common factor structure, where $F_t$ and $E_{it}$ are the common factors and the idiosyncratic components respectively, which can be either integrated of order 1 (I(1)) or integrated of order 0 (I(0)). Under strong exogeneity of $X_{it}$ for each i, panel statistics for the null hypothesis of no-cointegration can be derived from the model. Cointegration between $Y_{it}$ and $X_{it}$ exists only if the common and idiosyncratic components of the error term are both stationary. However, one problem of this framework is that it is difficult to interpret the case where cointegration exists if the cross-sectional dependence is persistent: the cointegration can exist between the cross sections and between the time series for each cross section in the panel (Dreger and Reimers, 2009).

Using the PANIC methodology from Bai and Ng (2004), Gengenbach, Palm and Urbain (2006) propose a sequential strategy for testing for no-cointegration when the panel data contains unobserved common factors, where they discuss the case when the nonstationarity in the data is solely driven by a reduced number of common stochastic trends and also the case where both common and idiosyncratic stochastic trends are present in the data. Based on the assumption that the panel series $Y_{it}$ (dependent variable) and $X_{it}$ (independent variables) are characterised by a factor structure, the test procedure is summarized as follows.

First, each panel variable $Y_{it}$ and $X_{it}$ is individually decomposed to the two parts of common factors and idiosyncratic components by conducting a PANIC analysis as suggested by Bai and Ng (2004). Then, the common factors and the idiosyncratic components are tested for unit roots respectively using the approach proposed by Bai and Ng (2004). Of course, the standard time series tests for unit roots can also be applied to the common factors and the panel unit root tests of the first generation can also be applied to the idiosyncratic components since the defactored series are independent by construction. Second, if I(1) common factors and I(0) idiosyncratic components are detected, then the non-stationarity in the panel entirely comes from a reduced number of common stochastic trends. Cointegration between $Y_{it}$ and $X_{it}$ occurs only if the common factors of $Y_{it}$ cointegrate with those of $X_{it}$. Standard cointegration tests for time series can be used to test whether cointegration exists between the estimated common factors of $Y_{it}$ and $X_{it}$; If both the common factors and idiosyncratic components are I(1), cointegration is then examined separately for each of the two parts. Standard panel tests for cointegration of the first type such as those of Pedroni (1999, 2004) can be used to test for cointegration between the estimated idiosyncratic components of $Y_{it}$ and $X_{it}$ (the defactored $Y_{it}$ and defactored $X_{it}$), and standard cointegration tests for time series can still be used to test whether cointegration exists between the estimated common factors of $Y_{it}$ and $X_{it}$. In this case, the null of no-cointegration between $Y_{it}$ and $X_{it}$ can be rejected only if the null hypothesis of no-cointegration is rejected for both the common factors and idiosyncratic components.

118

Of course, the approach is not flawless. The requirement of a large number of panel dimensions can be one of the important limitations. However, considering that the approach is superior to any other existing panel unit root test that takes cross-sectional dependence into consideration, it is employed in this dissertation to test the cointegration among panel variables of provincial output, labor, public capital and private capital. Finally, two popular cointegration tests for time series and panels suggested by Engle and Granger (1987) and Pedroni (1999, 2004) respectively are now briefly discussed because they are an indispensable part of the application of the sequential strategy proposed by Gengenbach, Palm and Urbain (2006).

Engle and Granger (1987) have developed a two-step procedure to test the null hypothesis of no-cointegration between a set of I(1) time-series variables. The first is to estimate the coefficients of a static relationship between dependent and independent variables in a regression equation by ordinary least squares. Second is to test the residuals from this regression for a unit root employing an augmented Dickey-Fuller test. Rejecting the null hypothesis of a unit root is an evidence in support of cointegration among these time-series variables.

Pedroni (1999) proposes several tests for the null hypothesis of no-cointegration using residuals obtained from the panel-version static regression analogous to that of Engle and Granger (1987) that also allows for considerable heterogeneity in the cointegration relationship. The cointegrating first-stage regression takes the form:

$$Y_{it} = \alpha_i + \delta_{it} + X_{it}^{'} \beta_i + \epsilon_{it}, \quad (5.17)$$

where i=1,..., N and t=1,..., T. $\beta_i=(\beta_{1i}, \beta_{2i}, ..., \beta_{Ki})'$, $X_{it}=(X_{1i,t}, X_{2i,t}, ... X_{ki,t})'$ and $\varepsilon_{it}$ is a disturbance error term. This specification allows for considerable heterogeneity since it allows for heterogeneous slope coefficients, fixed effects, and individual-specific deterministic time trends. Among the seven alternative panel cointegration statistics, five are nonparametric and the other two are parametric. The two parametric tests, which will be briefly discussed here, can be regarded as the panel analogue of augmented Dickey-Fuller tests. Based on the estimated residuals ($\varepsilon_{it}$) from estimating the first-stage regression individually for each panel member, the two tests are based on the regression:

$$\hat{\epsilon}_{i,t}=\eta_i \hat{\epsilon}_{i,t-1}+\sum_{q=1}^{q_i} \eta_{i,q} \Delta \hat{\epsilon}_{i,t-q}+v_{it} \quad (5.18)$$

Both tests have the null hypotehsis of no-cointegration and can be distinguished based on their their alternative hypothesis. For the panel t-test:

$$H_0 : \eta_i=1 \text{ for all } i ; \quad H_1 : \eta_i=\eta<1 \text{ for all } i \quad (5.19)$$

For the group t-test:

$$H_0 : \eta_i=1 \text{ for all } i ; \quad H_1 : \eta_i<1 \text{ for all } i \quad (5.20)$$

Moreover, Pedroni (1999) demonstrates that both test statistics follow an asymptotic standard normal distribution after some proper standardization procedures are conducted.

## 5.1.3 Panel Estimate of the Cointegration Vector

Although panel cointegration tests can be used to study whether a set of panel variables of the same order are cointegrated, they cannot provide any estimate of the possible cointegration vector or possible long-term equilibrium relationships. Some methods should be found or developed to estimate the regression coefficients in the panel cointegration models properly. Although the OLS estimator is asymptotically normal and consistent even in panel cointegrated models, it is still second-order asymptotically biased with invalid standard errors (Kao and Chen, 1995). Chen, McCoskey and Kao (1999) study the finite sample properties of the OLS estimator and the bias-corrected OLS estimator with the corresponding t-statistic and bias-corrected t-statistic respectively. Their research shows that the bias-corrected OLS estimator generally does not perform better than the OLS estimator, which prompts them to conclude that some alternatives of OLS estimator, which include the Fully Modified OLS (FMOLS) estimator and Dynamic OLS (DOLS) estimator, might be more appropriate for cointegrated panel regressions.

Pedroni (1996, 2000) proposes two Fully Modified OLS (FMOLS) estimators based on pooling along the 'within' and 'between' dimensions of the panel. Using Monte Carlo simulations, Pedroni demonstrates that the group mean panel FMOLS estimator, which pools the data along the between-dimension, exhibits relatively little small size distortion in small samples compared with the within-dimension panel FMOLS estimator. Moreover, in contrast to the within-dimension pooled panel FMOLS estimator, the

between-dimension group mean panel FMOLS estimator allows for heterogeneity of the cointegrating vector. In other words, heterogeneous coefficients for individual cross-section members rather than common slope coefficients are permitted for the between-dimension FMOLS estimator.

Kao and Chiang (2000) propose an alternative panel Dynamic OLS (DOLS) estimator. Also based on Monte Carlo simulations, they compare small sample properties of the two estimators of panel FMOLS and panel DOLS, both of which are obtained by pooling the data along the within-dimension of the panel. For the within-dimension panel FMOLS and DOLS estimators, Monte Carlo experiments show that the DOLS estimator has superior small sample properties while both of the FMOLS and DOLS estimators do not. However, Pedroni (2001) argues that the two within-dimension panel estimators of FMOLS and DOLS proposed by Kao and Chiang (2000) may suffer severe small sample size distortions. In particular, Pedroni (2001) points out that the point estimates from such within-dimension estimators are really economically uninterpretable in such cases when the heterogeneous cointegrating vectors exist. In contrast, Pedroni (2001) strongly recommends the between-dimension group mean panel FMOLS estimator as a superb one for cointegrated panel regressions. In particular, this estimator can account for the endogeneity of the regressors and also for serial correlation of the residuals in panel cointegrated models apart from the allowance for heterogeneity among individual cross-section panel members. Therefore, this estimator will be used for the estimation of the panel cointegration vectors in this dissertation.

The procedure to obtain the between-dimension group mean panel FMOLS estimator from Pedroni (2000) is briefly addressed here[48]. Consider the following cointegrated system for a panel of i=1,..., N and t=1,..., T:

$$Y_{it}=\alpha_i+\beta X_{it}+\mu_{it}$$
$$X_{it}=X_{it-1}+\epsilon_{it} \quad (5.21)$$

where $Z_{it}=(Y_{it}, X_{it})'\sim I(1)$ and $\omega_{it}=(\mu_{it}, \epsilon_{it})'\sim I(0)$ with asymptotic covariance matrix $\Omega_i$. $X_{it}$ is an m dimensional vector of regressors, which are not cointegrated with each other. $\omega_{it}=(\mu_{it}, \epsilon_{it})'$ are partitioned, which leads to a scalar series for the first element and an m dimensional vector of the first differences in the regressors $\epsilon_{it}=X_{it}-X_{it-1}=\Delta X_{it}$ for the second element. Then $\Omega_i$ is constructed as:

$$\Omega_i=\begin{bmatrix} \Omega_{11i} & \Omega'_{21i} \\ \Omega_{21i} & \Omega_{22i} \end{bmatrix} \quad (5.22)$$

where $\Omega_{11i}$ is the scalar long run variance of the residual $\mu_{it}$, $\Omega_{22i}$ is an $m \times m$ matrix that gives the long run covariance among the residual $\epsilon_{it}$, and $\Omega_{21i}$ is an $m \times 1$ vector of the long run covariance between the residual $\mu_{it}$ and each $\epsilon_{it}$. Set the asymptotic covariance matrix $\Omega_i$ as: $\Omega_i=L_i L_i'$, where $L_i$ is the lower triangular matrix of $\Omega_i$. The elements of $L_i$ are as follows:

$$L_{11i}=(\Omega_{11i}-\Omega^2_{21i}/\Omega_{22i})^{1/2}, \ L_{12i}=0, \ L_{21i}=\Omega_{21i}/\Omega^{1/2}_{22i}, \ L_{22i}=\Omega^{1/2}_{22i}. \quad (5.23)$$

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[48]Technical details can be found in Pedroni (2000).

123

Meanwhile, $\Omega_i$ can also be decomposed as $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$, where $\Omega_i^0$ is the contemporaneous covariance and $\Gamma_i$ is a weighted sum of autocovariances. Then, the between-dimension group mean panel FMOLS estimator for the coefficient β is given as:

$$\hat{\beta}_{NT} = N^{(-1)} \sum_{i=1}^{N} \left( \sum_{t=1}^{T} (X_{it} - \bar{X}_i)^2 \right)^{-1} \left( \sum_{t=1}^{T} (X_{it} - \bar{X}_i) Y_{it}' - T\hat{Y}_i \right), \quad (5.24)$$

where $\bar{X}_i$ and $\bar{Y}_i$ are the individual specific means, and set:

$$Y_{it}' = (Y_{it} - \bar{Y}_i) - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \Delta X_{it}, \quad \hat{Y}_i \equiv \hat{\Gamma}_{21i} + \hat{\Omega}_{21i}^0 - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} (\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^0). \quad (5.25)$$

The t-statistic associated with the estimator asymptotically follows a standard normal distribution.

## 5.2 Infrastructure and Productivity: A Panel Granger Causality Test

The Granger test, first introduced by Granger (1969), has become one of the most popular methodologies for investigating the nature of the casual relationship between two variables. The standard definition of Granger causality, given by Granger (1969), can be stated that variable x is Granger causing variable y if y can be best predicted by using all available information than by using the information except from x. Specifically, the null hypothesis that x does not Granger cause y can be evaluated based on the regression of y on both lagged values of y and lagged values of x. The null hypothesis can be rejected if one or more of the lagged values of x is statistically significant, which indicates that x

Granger causes y. Of course, the Granger test is not flawless. It cannot fully ascertain the exact nature of a causal relationship between two variables. Moreover, the relationship, revealed by the Granger test between x and y, might be caused by some other variable z on x and y simultaneously. However, these weaknesses do not prevent the Granger test from being an established and useful method for studying the causal relationship between two variables.

Although originally designed for time series pairs, Granger tests have been modified by some researchers to evaluate causal relationships in panel data (Holtz-Eakin, Newey, and Rosen, 1988; Arellano and Bond, 1991; Hurlin and Venet, 2001; Hurlin, 2004). The application of the original Granger methodology in the context of panel data can be justified by the main reason that the panel analysis is generally preferable to the traditional time series analysis. In particular, Hurlin and Venet (2001) point out that panel Granger tests can produce more meaningful results with shorter time periods and generate more efficient results than conventional Granger tests by incorporating much more observations.

A representative example of early panel causality tests is proposed by Holtz-Eakin, Newey, and Rosen (1988), which can be specified as:

$$y_{it} = \alpha_0 + \sum_{j=1}^{q} \alpha_j y_{i,t-1} + \sum_{j=1}^{q} \beta_j x_{i,t-1} + f_i + \mu_{it}, \quad (5.26)$$

where i=1,..., N and t=1,..., T. $f_i$ is the fixed effects and $\mu_{it}$ is a disturbance error term. Then equation (5.26) is first differenced to eliminate the fixed effects $f_i$, resulting in the model below:

$$y_{it} - y_{i,t-1} = \sum_{j=1}^{q} \alpha_j (y_{i,t-j} - y_{i,t-j-1}) + \sum_{j=1}^{q} \beta_j (x_{i,t-j} - x_{i,t-j-1}) + (\mu_{it} - \mu_{i,t-1}) \quad (5.27)$$

A Two-Stage Least Squares (2SLS) procedure with a set of time-varying instrument variables is employed to estimate the equation due to the simultaneity issue introduced in equation (5.27). Finally, the null hypothesis that x does not Granger cause y is given as: $\beta_j = 0 \, \forall \, j = 1,..., q$ and the alternative hypothesis is given as: $\beta_j \neq 0 \, \forall \, j = 1,..., q$. One severe problem of the model discussed above is the assumption that the coefficients on the explanatory variables are the same across all cross sections in the panel, which means that either causality occurs for each cross-section or it does not occur for any cross- sections in the panel. This is a very strict and even unrealistic restriction since it is very common in reality that one variable may Granger cause another variable for some but not all the cross-sections in the panel (i.e., causal variation across units).

Hurlin (2004) proposes a Granger non causality test in heterogeneous panel data models with fixed coefficients, where the heterogeneity across individual cross-sections in terms of the causal relationship is considered. Meanwhile, two conceptual issues arising from any panel Granger causality test are clarified by Hurlin (2004). One issue comes from determining the optimal information set that can be used to forecast variable y if variable x and variable y are observed on K individuals. Although it is very likely that the variable

x observed on the ith individual can Granger cause the variable y observed on the jth individual where i=j or i≠j, Hurlin (2004) assumes that the Granger causality from x to y exists if and only if the past values of x observed on the ith individual improve prediction of y observed on the ith individual exclusively. In other words, this model only tests the Granger causal relationship for a given unit in the panel. Following the same tradition as Holtz-Eakin, Newey, and Rosen (1988), Hurlin (2004) also believe that the cross-sectional information is only used to improve the model specification and test power.

The other issue concerns the specification of the test hypothesis for the panel Ganger causality test. As to the null hypothesis, Hurlin (2004) assumes that no causal relationship from x to y exists for all the cross-sections in the panel, which is called the Homogeneous Non Causality (HNC) hypothesis. As to the alternative hypothesis, Hurlin (2004) assumes that a causal relationship from x to y exists for at least one cross-section in the panel, which is then called the Heterogeneous Non Causality (HENC) hypothesis. In contrast, the alternative hypothesis of the Granger panel causality test proposed by Holtz-Eakin, Newey, and Rosen (1988) is actually a Homogeneous Causality (HC) hypothesis, which implies that there exists a causal relationship from x to y for all the cross-sections in the panel. Therefore, the alternative hypothesis in the test of Hurlin (2004) is more reasonable and realistic in application than that in the test of Holtz-Eakin, Newey, and Rosen (1988), which naturally makes the panel Granger causality test of Hurlin (2004) an ideal candidate for investigating the causal relationship between output and public capital in China.

Here, the panel test of the Granger Non Causality hypothesis, proposed by Hurlin (2004), is briefly presented. Let x and y be two covariance stationary variables, observed on N units and T periods. Consider the following heterogeneous autoregressive linear model:

$$y_{i,t} = \alpha_i + \sum_{l=1}^{L} \gamma_i^{(l)} y_{i,t-l} + \sum_{l=1}^{L} \beta_i^{(l)} x_{i,t-l} + \epsilon_{i,t}, \quad (5.28)$$

where i=1,..., N and t=1,..., T. $\alpha_i$ is the fixed effects and $\beta_i = (\beta_i^{(1)}, ..., \beta_i^{(L)})'$. The lag order L is identical for all cross-sectional units of the balanced panel. Both of the autoregressive parameters $\gamma_i^{(l)}$ and regression coefficients $\beta_i^{(l)}$ are allowed to differ across units but are set to be constant. So this model is a fixed coefficients one with fixed individual effects. For each unit i=1,..., N, the error $\epsilon_{i,t} \forall t = 1,... T$ are normally independent and identically distributed (i.i.d.) with zero mean and finite heterogeneous variances across units and are independently distributed across units. In this heterogeneous panel model, the null hypothesis assumes that there does not exist a causality relationship from x to y for any of the N individual units in the panel. The Homogeneous Non Causality (HNC) hypothesis can be formally stated as:

$$H_0: \beta_i = 0 \,\forall\, i = 1,..., N, \quad (5.29)$$

where $\beta_i = (\beta_i^{(1)}, ..., \beta_i^{(L)})'$. The alternative hypothesis assumes that there exists a causality relationship from x to y for at least one unit in the panel. Suppose there are $N_1$ ($N_1 < N$) individual units with no causality from x to y and the alternative hypothesis can be defined as:

128

$$H_1 : \beta_i = 0 \, \forall \, i = 1,\ldots, N_1, \, \beta_i \neq 0 \, \forall \, i = N_1 + 1, N_1 + 2, \ldots, N, \quad (5.30)$$

where $N_1$ is unknown but satisfies: $0 \leq N_1 < N$. Let $W_{N,T}^{HNC}$ be an average statistic and defined as:

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T}, \quad (5.31)$$

where $W_{i,T}$ denotes the Wald statistic for the i$^{th}$ unit in the panel associated with the individual test of $H_0$: $\beta_i = 0$ for each i=1,...,N. The approximated standardized statistic to be used in this dissertation, which was proposed by Hurlin (2004), is given below.

$$Z_{NT}^{HNC} = \sqrt{\frac{N}{2 \times L} \times \frac{(T - 2L - 5)}{(T - L - 3)}} \times [\frac{(T - 2L - 3)}{(T - 2L - 1)} W_{NT}^{HNC} - L]. \quad (5.32)$$

This statistic converges to N(0,1) in distribution as N→∞ with T > 5 + 2L.

## 5.3 Estimates of Infrastructure Stocks for China, 1987-2003

In order to investigate the productive effects of public capital in China econometrically, public capital stock data for China must be available for such investigations. Since no public capital stock data for China has been provided by the official authorities, estimates of such data must be made by individual researchers. Although some researchers have estimated time series data of public capital stock for China in their studies in recent years (Ma, 2000; Lou, 2003; Fan et al., 2004; Zhu, 2004; Wang, 2006), panel data of public capital stock across Chinese regions have seldom been estimated. Therefore, this section

attempts to provide annual public capital stock estimates for China across regions for the period 1987-2003 using the perpetual inventory method.

The perpetual inventory method, which was first developed by Goldsmith (1951), has been one of the most standard and popular methods used to measure capital stocks in a variety of research contexts. Applying this method to the estimation of the public capital stocks across regions in China, the net public capital stock at the end of the current year t for the $i^{th}$ region, $G_{i,t}$, is the result of the net public capital stock at the end of the previous year (t-1) for the $i^{th}$ region, $G_{i,t-1}$, of gross public investment in the current year t for the $i^{th}$ region, $I_{i,t}$, and of the depreciation in the current year t for the $i^{th}$ region, $D_{i,t}$:

$$G_{i,t} = G_{i,t-1} + I_{i,t} - D_{i,t}. \quad (5.33)$$

where i=1,..., N and t=1,..., T. Suppose geometric depreciation which means that the public capital stock depreciates at a rate of $\delta_{it}$ for the $i^{th}$ region and year t, then the equation (5.33) can be re-expressed as:

$$G_{i,t} = G_{i,t-1}(1 - \delta_{i,t}) + I_{i,t}. \quad (5.34)$$

where i=1,..., N and t=1,..., T. From the theoretical perspective, the term $G_{i,t-1}$ in the equation (5.34) can be repeatedly substituted to get the following equation:

$$G_{i,t} = \sum_{q=1}^{\infty} (1 - \delta_{i,t})^q I_{i,t-q}. \quad (5.35)$$

where the net public capital stock at the end of the current year t for the $i^{th}$ region, $G_{i,t}$, is a weighted sum of past public investments with i=1,..., N and t=1,..., T. Because the number of the past public investment series is finite in reality, the equation (5.35) is replaced by the following more realistic one as:

$$G_{i,t}=(1-\delta_{i,t})^t G_{i,0}+\sum_{q=1}^{t-1}(1-\delta_{i,t})^q I_{i,t-q}. \quad (5.36)$$

where $G_{i,0}$ is the initial public capital stock at the beginning of year 1 for the $i^{th}$ region with i=1,..., N and t=1,..., T.

According to equation (5.36), the following three inputs are required in the application of the perpetual inventory method based on the geometric depreciation pattern to estimate public capital stocks across regions in China. First, a time series on public investment flows for each region in China is needed. Second, the depreciation rate should be determined. Third, the initial public capital stock for each region at the beginning of year 1 is also needed. These three issues are addressed below.

The determination and attainment of a region-level panel data for public investments in China are not easy to achieve considering the fact that no data explicitly designed for such type are directly available from any official authority in China. Since the only available data that are highly related to public investments in China are the annual investments in fixed assets by sectors in China, several researchers suggest that the public investment data may be estimated based on this kind of data (Ma, 2000; Lou, 2003; Fan et al., 2004; Zhu, 2004; Wang, 2006). Therefore, the same tradition is followed in this

dissertation. Among the sixteen sectors that disaggregate the total investments in fixed assets, the sector of transportation, storage, postal and telecommunication services and the sector of production and supply of electric power, gas and water are considered as potential candidates for the estimates of public investments in China in that the two sectors fully coincide with the definition of public infrastructure made in the dissertation before. However, since the time span for the available data of the investments in fixed assets for the sector of production and supply of electric power, gas and water is much shorter than that for the sector of transportation, storage, postal and telecommunication services, only the investments in fixed assets[49] for the sector of transportation, storage, postal and telecommunication services are finally employed to estimate the annual region-level public investments in China for the period 1987-2003 with 29 regions included.

Three points should be further explained. First, the consistent data on the investments in fixed assets for the sector of transportation, postal and telecommunication services are only available for the period 1986-2003. Second, China has 31 provinces, autonomous regions and municipalities under the direct control of the central government when excluding the three regions of Taiwan, Hong Kong and Macao. Taiwan has not been effectively controlled by the central government since 1949. Hong Kong and Macao became Special Administrative Regions of China only in 1997 and 1999 respectively. Therefore, these three regions are not included in the research. Tibet is excluded from the research for the main reason of missing data. Moreover, although Chongqing area, which

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[49]Investment in fixed assets by sector mainly covers the two parts of the investment in capital construction and the investment in innovation.

is originally a part of Sichuan province, was separated from Sichuan province and became an independent municipality in 1997, the research still combines Sichuan and Chongqing together as a whole province of Sichuan as if they had not been separated yet for the consistency of the data. In summary, a panel data set for public investments of 29 regions (provinces, autonomous regions and municipalities) for a period of 17 years (1987-2003) is established. Third, since the time-series data of the investments in fixed assets for each region are originally given in prices of current year, these data are then price-adjusted so that all the investments in fixed assets reflect a common price level[50].

The determination of the depreciation rate ($\delta_{it}$) is based on the following simple assumption that the depreciation rate is both time-invariant and region-invariant:

$$\delta_{i,t} = \delta_i = \delta \ \forall i = 1, ..., N, \ t = 1, ..., T \quad (5.37)$$

Then, based on the existing research on the determination of the depreciation rate (Xie, 2001; Lou, 2003; Ma, 2003; Fan et al., 2004), the depreciation rate is set at 5%.

As to the determination of the initial public capital stock for each region at the beginning of year 1 (the end of year 1986 in the research), the method developed by Hall and Jones (1999) in estimating the initial physical capital stocks for 127 countries in 1960 is used here. Specifically, the initial value of the public capital stock at the end of year 1986 for the $i^{th}$ region is given as:

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[50]Investments in fixed assets data are price-adjusted to the common price level in the base year of 1952. The fixed assets price index data are available in China Statistical Yearbook (1987-2003).

$$G_{i,0} = G_{i,1986} = \frac{I_{i,1986}}{g_i + \delta} \quad (5.38)$$

where $g_i$ is calculated as the geometric average growth rate for 1986-1996 of the public investment series for the $i^{th}$ region in China and $\delta$ is the depreciation rate with the assumed value of 5% in the dissertation. A representative sample data for the estimation of public capital stocks across regions in China are given in section 5.4 below.

## 5.4 Measurement of Variables and Data

The choice of study period is very important in economic growth and development studies. Two studies that are almost the same except for the study period are very apt to produce different conclusions on the same research question. The study period of the dissertation covers 17 years from 1987 to 2003, during which the Chinese economy had experienced rapid growth, accompanied with huge increases in public investments and public capital stocks in China. Moreover, although a study with a longer time period may be better, the inconsistency and even unavailability of such data on public capital stocks in China have made such a study impossible and even unrealistic.

The choice of spatial scale for analysis is also very important in economic studies. It is very likely that two studies that are almost the same except for the spatial scale for analysis will produce different or even reverse results. Although a variety of studies on the productive effects of public capital have been conducted in the past two decades, most of them emphasize developed countries. The research results and conclusions from these studies may not be directly applied to developing or emergent countries like China.

The analysis is conducted on the regional level in China. Specifically, these regions refer to provinces, autonomous regions and municipalities in People's Republic of China (P.R.C.). The main reason for selecting province as the spatial scale is that the related data for this dissertation can only be available at the provincial level in China. However, it should be noted that using the province as the spatial scale for analysis will surely mask many variances at the sub-provincial level, which requires further studies on the productive effects of public capital in China once the data at the sub-provincial level in China might be available in future.

China has 31 provinces, autonomous regions and municipalities under the direct control of the central government when excluding the three regions of Taiwan, Hong Kong and Macao. As above in section 5.3, the three regions of Taiwan, Hong Kong and Macao are not included and considered in the research for the main reason that their economic development levels and political institutions have been relatively independent and are different from Mainland China. The 31 provinces, autonomous regions and municipalities of Mainland China can be divided into three mega-regions geographically: the eastern, the central and the western mega-regions[51]. In terms of economic development, the eastern mega-region leads the other two mega-regions while the western mega-region is least developed. Moreover, Tibet is excluded from the research for the missing data. Although Chongqing area, which is originally a part of Sichuan province, was separated from Sichuan and became an independent municipality in 1997, the research still

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[51]The specific components of each mega-region have been specified before.

combines Sichuan and Chongqing together as a whole province of Sichuan as if they had not been separated yet based on the consideration of data consistency.

In this dissertation, two kinds of econometric models are established to investigate the nature of the relationship between economic output and public capital in China. For the first kind of model, where a nonstationary panel analysis is conducted on a regional level aggregate Cobb-Douglas production function. The production function includes public capital, private capital and labor as the three inputs in the China context. For the dependent variable, regional economic output ($Y_{it}$) is measured by the annual real Gross Domestic Product (GDP) at 1952 constant price by region in China. Among the three independent variables, the labor ($L_{it}$) is measured by the product of annual total number of persons employed and annual average years of education at the regional level in China, which makes the labor variable not only a measure of workforce quantity for a region but also that of workforce quality (human capital) for the region. The other two dependent variables of public capital ($G_{it}$) and private capital ($K_{it}$) are measured by annual public capital stocks and annual private capital stocks respectively at 1952 constant price by region in China. Moreover, as a kind of extension to the original log-linear Cobb-Douglas model, the spillovers variable ($S_{it}$), which is the average of the public capitals for a region's first-order neighboring regions, is added to the original model to test for the spillover effects of public capital among Chinese regions. For the second model, where a panel Granger causality test is conducted to investigate the causal relationship between the two variables of economic output and public capital at the regional level in China, the

measurements of the two variables ($Y_{it}$ and $G_{it}$) are exactly the same as their counterparts in the first model.

Data for 29 regions of China for a period of 17 years (1987-2003) are used in the dissertation. For the variable of regional economic output ($Y_{it}$), the data of real GDP is directly collected and then calculated from China Statistics Yearbook from 1987 to 2004. Moreover, the GDP deflators that are used to convert nominal GDP to real GDP are also available from China Statistics Yearbook from 1987 to 2004.

For the variable of labor ($L_{it}$), the data of the total number of persons employed are obtained from China Statistics Yearbook from 1987 to 2004; the data of average years of education before 2000 is available in Cheng et al. (2004) and the data after 1999 is updated using China Population Statistics Yearbook from 2001 to 2004.

For the variable of public capital ($G_{it}$), the estimation method for public capital stocks has been discussed in detail in the previous section 5.3. The data of the investments in fixed assets for the sector of transportation, storage, postal and telecommunication services (i.e., representing the public investments) before 2001 is obtained from Statistics on Investment in Fixed Assets of China: 1950-2000 and the data after 2000 is from China Statistics Yearbook from 2001 to 2004. Moreover, the data of the fixed assets price index, which is used to price-adjust the nominal investments in fixed assets to the common price level in the base year of 1952, are also available in China Statistical Yearbook from 1987 to 2004.

For the variable of private capital ($K_{it}$), a two-step procedure is used to obtain the data for private capital stocks. First, a panel data set on the capital stocks at the regional level in China from 1987 to 2003 is constructed, where the data before 2001 are available from Zhang et al. (2004) and the data after 2000 are updated using the same estimation methodology as that of Zhang et al. (2004) based on China Statistics Yearbook from 2002 to 2004. Second, the data for the private capital stocks are obtained by subtracting the public capital stocks data from the corresponding capital stocks data. In other words, the capital stocks data are decomposed into the two parts of the public capital stocks data and private capital stocks data.

Finally, spillover variable ($S_{it}$), which is directly derived from the public capital variable ($G_{it}$), is the product of $G_{it}$ and the spatial weight matrix W based on the first-order contiguity relations for each region in China.

All real values are expressed in Chinese local currency (RMB). The main official sources for data include:

NSB (National Statistical Bureau) (1987-2004), China Statistical Yearbook, Beijing, China, China Statistical Press (in Chinese)

NSB (National Statistical Bureau) (2002), Statistics on Investment in Fixed Assets of China: 1950-2000, Beijing, China, China Statistical Press (in Chinese)

The table below gives a summary statistics of all variables in selected years.

*Table 10: Summary Statistics of Main Variables in Selected Years*

| Region | GDP (100 Million) | | Public Capital (100 Million) | | Private Capital (100 Million) | | Labor (10,000 persons × year) | |
|---|---|---|---|---|---|---|---|---|
| | 1987 | 2003 | 1987 | 2003 | 1987 | 2003 | 1987 | 2003 |
| **Eastern Mega-Region** | | | | | | | | |
| **Beijing** | 286.8 | 1382.7 | 40.9 | 680.1 | 698.9 | 6579.1 | 4688.5 | 8882.8 |
| **Tianjin** | 170.5 | 831.5 | 42.1 | 245.5 | 367.1 | 1778.2 | 3231.8 | 3880.5 |
| **Hebei** | 364.9 | 2064.3 | 14.3 | 462.7 | 497.5 | 3732.9 | 15936.1 | 28398.6 |
| **Liaoning** | 605.8 | 2316.8 | 53.1 | 238.3 | 328.3 | 1485.2 | 11960.8 | 16603.7 |
| **Shanghai** | 656.9 | 3359.1 | 57.4 | 559.3 | 803.1 | 5298.3 | 5757.4 | 7812.5 |
| **Jiangsu** | 490.5 | 3282.9 | 23.0 | 716.7 | 735.7 | 6893.2 | 19620.0 | 27764.6 |
| **Zhejiang** | 338.3 | 2241.8 | 13.0 | 550.9 | 409.0 | 4270.5 | 13705.5 | 22984.3 |
| **Fujian** | 160.1 | 1190.5 | 6.7 | 233.5 | 201.4 | 1252.9 | 6709.8 | 13328.0 |
| **Shandong** | 513.1 | 3215.3 | 44.8 | 632.0 | 967.4 | 7655.1 | 20801.7 | 38085.5 |
| **Guangdong** | 336.4 | 2613.3 | 42.4 | 956.2 | 555.2 | 5081.3 | 13170.7 | 32989.6 |
| **Guangxi** | 133.7 | 610.2 | 7.7 | 226.4 | 196.4 | 1059.7 | 10967.9 | 20207.3 |
| **Hainan** | 24.0 | 132.8 | 1.9 | 228.7 | 56.4 | 115.6 | 1636.4 | 2897.8 |
| **Central Mega-Region** | | | | | | | | |
| **Shanxi** | 168.4 | 701.3 | 27.3 | 375.1 | 356.1 | 1968.5 | 7629.7 | 12341.3 |
| **Inter Mongolia** | 138.9 | 629.5 | 21.4 | 280.9 | 209.5 | 1268.4 | 5342.7 | 7809.2 |
| **Jilin** | 168.1 | 695.8 | 7.3 | 115.6 | 234.2 | 1087.6 | 6692.1 | 9090.0 |
| **Heilongjiang** | 231.9 | 843.0 | 39.1 | 241.4 | 459.9 | 1302.9 | 8462.3 | 13643.8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Anhui** | 142.8 | 671.9 | 15.2 | 177.9 | 179.0 | 622.5 | 13303.8 | 26178.2 |
| **Jiangxi** | 128.7 | 654.9 | 7.2 | 192.7 | 201.6 | 1011.6 | 9362.8 | 16357.2 |
| **Henan** | 290.2 | 1363.1 | 12.5 | 448.6 | 629.7 | 3444.9 | 21807.1 | 44101.1 |
| **Hubei** | 244.3 | 1155.9 | 12.5 | 327.0 | 228.8 | 1489.6 | 13697.7 | 20095.4 |
| **Hunan** | 227.4 | 936.6 | 7.0 | 259.3 | 408.1 | 1491.6 | 17081.6 | 28308.2 |
| **Western Mega-Region** | | | | | | | | |
| **Sichuan** | 271.8 | 1539.6 | 35.2 | 685.7 | 1063.5 | 3985.8 | 21379.3 | 45303.6 |
| **Guizhou** | 55.7 | 197.4 | 3.8 | 127.6 | 200.5 | 668.2 | 6648.2 | 14593.0 |
| **Yunnan** | 124.0 | 509.3 | 13.3 | 280.5 | 62.8 | 118.7 | 8172.9 | 14192.7 |
| **Shanxi** | 164.7 | 691.5 | 23.3 | 268.4 | 452.5 | 1501.8 | 8355.6 | 15503.5 |
| **Gansu** | 120.4 | 517.1 | 11.0 | 317.8 | 328.2 | 1211.8 | 5516.3 | 9176.7 |
| **Qinghai** | 25.3 | 87.7 | 4.3 | 55.1 | 54.2 | 237.4 | 843.4 | 1708.9 |
| **Ningxia** | 37.3 | 145.2 | 3.0 | 48.4 | 67.4 | 221.7 | 1013.8 | 2135.2 |
| **Xinjiang** | 95.5 | 409.7 | 22.6 | 193.8 | 197.3 | 1154.3 | 3448.0 | 6041.4 |
| **National Average** | 231.6 | 1206.6 | 21.1 | 349.2 | 384.5 | 2344.5 | 9894.6 | 17600.5 |

Source: Based on China Statistical Yearbook (1987-2004), Statistics on Investment in Fixed Assets of China: 1950-2000, Cheng et al. (2004) and Zhang et al. (2004).

Notes: GDP, public capital and private capital for 1987 and 2003 are in RMB of 1952 constant value; the labor variable is measured by the product of annual total number of persons employed and annual average years of education.

## 5.5 Summary

In this research, a nonstationary panel analytical procedure, that includes the three logically consistent steps of panel unit root test, panel cointegration test and panel estimate of the cointegration vector, is specified to study the productive effects and spillover effects of public infrastructure in China. A panel Granger causality test is also introduced to investigate the relationship between infrastructure and productivity in China. For both of the two studies, the primary study period is from 1987 to 2003 and the primary spatial unit for analysis is the region (i.e., province or municipality in China). The data used in the research are mainly from China National Statistical Bureau and some other related sources. Moreover, the infrastructure stocks for China from 1987 to 2003 are estimated using the perpetual inventory method in the research due to the nonexistence of official data on this variable.

# 6 Public Infrastructure and Regional Productivity in China

Using a panel dataset covering 29 regions of China over the period of 1987-2003, the chapter reports on an empirically examination of the relationship between infrastructure and regional productivity in China. The first section conducts the three-step nonstationary panel analytical procedure to investigate the productive and spillover effects of public capital in China. The second section employs a panel Granger causality test to assess the possible causal relationship between public capital and productivity in China. The final section concludes.

## 6.1 A Nonstationary Panel Analysis of Infrastructure and Productivity in China

In the past two decades, China's public infrastructure investments have experienced a rapid growth from relatively low public capital stocks with inadequate capacity and poor-quality public services. Almost during the same period, China went through an astonishing economic growth and development induced in part with public policies that changed its historic institutions. More importantly, public infrastructure investments in China grew even faster than the economy did. As demonstrated in Chapter 3, the share of infrastructure investments in the nominal GDP has increased from 3.90% in 1985 to

9.47% in 2007. Under this background, it is natural to ask whether public infrastructures or public capital stocks have productive effects on China's economy during the last two decades. This issue is just one of the important questions the dissertation attempts to answer.

Based on the enormous existing literature that attempts to study the productive effects of public capital on economic outputs mainly in industrialized countries, the aggregate Cobb-Douglas production function framework that is popularly used in these literatures is applied in the dissertation on China. As demonstrated in Chapter 5, for the aggregate Cobb-Douglas production function model in the natural logarithmic form, the log of regional GDP is regressed against the logs of regional public capital, private capital and labor with great attention paid to the estimated elasticity of public capital. A statistically significant and positive value for the estimated elasticity of public capital indicates that public capital does have productive effects on economic outputs. As to the selection of the estimation method for the model, the intrinsic nature of the economic variables employed in the research plays a critical role in the determination of the estimation method. Figure 9 below provides the trends of GDP, public capital, private capital and labor all in the natural logarithmic forms in China for the period 1987-2003. It shows that all four economic variables of GDP, public capital, private capital and labor seem to be nonstationary with almost similar trend-patterns, which means that a long-run relationship or cointegration may exist among the four variables in the model. Therefore, the analytical techniques for nonstationary models may be suitable for the research. More importantly, the availability of a panel data set for GDP, public capital, private capital and

labor at the region level in China as well as the new developments in nonstationary panel models does make it possible and feasible to study the productive effects of public capital on economic outputs in China.
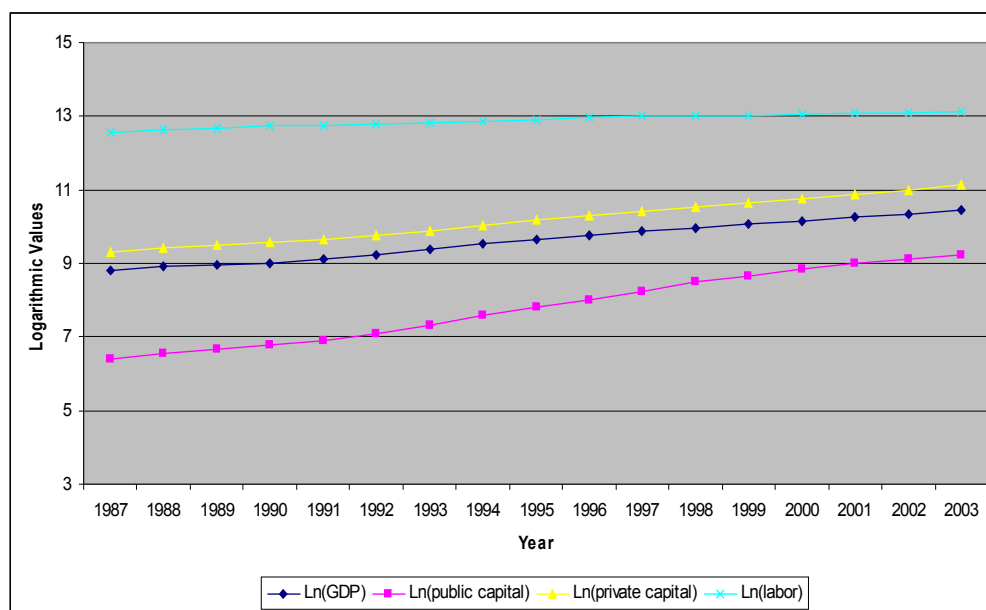


*Note: Calculation is based on data of 29 regions in China (Tibet is excluded and Chongqing is combined with Sichuan)*

*Source: Based on Statistics on China's Statistical Yearbook 1988-2004*

*Figure 9: Trends of GDP, Public Capital, Private Capital and Labor (taking natural logarithmic forms) in China, 1987-2003*

In this section, a nonstatioanry panel analytical framework is employed to study the nature of the relationship between public capital and economic outputs based on the aggregate panel Cobb-Douglas production function model. As discussed in Chapter 5, a three-step procedure of panel unit root tests, panel cointegration tests and panel estimates

of the cointegration vector are conducted sequentially to investigate the productive and spillover effects of public capital at the region level in China.

## 6.1.1 Panel Unit Root Test

The main purpose of the panel unit root test is to determine whether the four variables of GDP, public capital, private capital and labor (all in the natural logarithm) at the region level in China from 1987 to 2003 are nonstationary, where a two-step procedure is conducted with two kinds of tests undertaken respectively. For the first step, the CD diagnostic test for cross-section dependence in panels proposed by Pesaran (2004) is used to check whether the cross-section dependence is present for each of the four variables (all in the natural logarithm).

Since the CD test statistic is calculated based on the estimated residuals of the ADF regression for each cross-section in the panel, the lag order (the number of augmenting lagged dependent variable) for each ADF test must be determined for each cross-section in the panel. Here, the method proposed by Ng (2001) is used to determine the optimal lag order for each cross-section in the panel and for each of the four variables[52]. Based on the Gauss code developed by Ng (2001), the lag order is calculated with the single value of zero for each cross-section in each of the four variables in levels and in first-difference. However, the CD statistics corresponding to the lag order with values of one and two besides zero are also calculated to provide comprehensive results for the CD test. The test results are given in Table 11 below.

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[52]The technical details for the method is not discussed here and can be found in Ng and Perron (2001).

*Table 11: CD Diagnostic Tests for Cross Section Dependence in Panels*

| Variable | Sample period | CD test (lag=0) | | CD test (lag=1) | | CD test (lag=2) | |
|---|---|---|---|---|---|---|---|
| | | Levels | First-differences | Levels | First-differences | Levels | First-difference |
| GDP | 1987-2003 | 50.60*** | 43.93*** | 48.71*** | 13.88*** | 17.87*** | 14.40*** |
| Labor | 1987-2003 | 15.63*** | 17.60*** | 14.51*** | 17.18*** | 12.02*** | 11.71*** |
| Private Capital | 1987-2003 | 27.42*** | 27.86*** | 24.55*** | 10.70*** | 12.59*** | 11.56*** |
| Public Capital | 1987-2003 | 47.62*** | 28.58*** | 32.38*** | 27.52*** | 29.09*** | 24.94*** |

Note: The panel consists of 29 regions with annual data of 17 years in China. All variables at the region level are in the natural logarithmic forms. *** denote statistical significance at the 1 percent level. The CD statistic has an asymptotic standard normal distribution under the null hypothesis of no cross-section dependence. The ADF test equation for the variables both in levels and in first differences contains region-specific intercepts, linear time trends and three cases for lag orders of zero, one and two for the respective variable. The tests are carried out using the MATLAB procedures written by the author.

Table 11 above clearly indicates strong cross-section dependence for all four variables in levels and in first-differences when the lag order equals zero, one and two. Therefore, the panel unit root test that considers cross section dependence among units in the panel should be used to check the nonstationarity of the four variables of GDP, labor, private capital and public capital in both levels and first differences at the region level in China from 1987 to 2003, which naturally leads to the second step of the two-step procedure.

For the second step, the panel unit root test robust to cross-section dependence in heterogeneous panels proposed by Pesaran (2005) is used to check the nonstationarity of the four variables in levels and in first differences. Summarized results of the panel unit

root test conducted on the four variables in both levels and first differences are given below.

*Table 12: Panel Unit Root Tests*

| Variable | Sample period | Pesaran's CIPS test (lag=1) | | Degree of Integration |
|---|---|---|---|---|
| | | Levels | First-differences | |
| GDP | 1987-2003 | 3.39 | -3.13*** | I(1) |
| Labor | 1987-2003 | 0.12 | -3.53*** | I(1) |
| Private Capital | 1987-2003 | 0.63 | -3.13*** | I(1) |
| Public Capital | 1987-2003 | -0.64 | -1.63** | I(1) |

Note: The panel consists of 29 regions with annual data of 17 years in China. All variables at the region level are in the natural logarithmic forms. ***, ** denote statistical significance at the 1, 5 percent level respectively. The table gives the standardized t-bar statistic for the Pesaran's CIPS (2005) test. The test statistic has an asymptotic standard normal distribution under the null hypothesis of nonstationarity. The test equation for each variable in levels contains region-specific intercepts, linear time trends and lag order of one for each respective variable. The test equation for each variable in first differences also contains region-specific intercepts, linear time trends and lag order of one for each respective variable. The tests are carried out using the Stata built-in module *"pescadf"*.

From the table above, the Pesaran's CIPS (2005) test strongly suggests that all the variables of GDP, labor, private capital and public capital are nonstationary in levels, but then become stationary in first differences. Therefore, the four variables of GDP, labor, private capital and public capital are all integrated of the same order one, which then establishes a solid theoretical basis for the cointegration analysis in the next section below.

## 6.1.2 Panel Cointegration Test

Since cross-section dependence exists in each of the four nonstationary variables of GDP, labor, private capital and public capital that are all integrated of the same order one, the sequential strategy for testing for no-cointegration proposed by Gengenbach, Palm and Urbain (2006), who assume that cross-sectional dependence comes from a common factor structure, is used here to conduct the panel cointegration test for the four variables in the research. The testing procedure can be divided into the following three steps.

First, each nonstationary variable of GDP, labor, private capital and public capital is decomposed to the two parts of common factors and idiosyncratic components by conducting a PANIC analysis as suggested by Bai and Ng (2004), where the cross-section dependence in each of the original variables are assumed to come from the common factors and then the idiosyncratic components are cross-section independent by construction. The number of common factors for each variable is mainly determined in such a new way that the assumption of cross-section independence for the idiosyncratic components at the levels is satisfied as best as possible under a certain scenario combined with the BIC3 criteria proposed by Bai and Ng (2002). It turns out that a single factor model for each of the three variables of GDP, labor, public capital and a two-factor model for the variable of private capital yields the idiosyncratic components where the assumption of cross-section independence is best satisfied than other factor models are. Summarized results of the CD tests (Pesaran, 2004) for cross-section dependence in the idiosyncratic component part of each variable are given below.

*Table 13: CD Diagnostic Tests for Cross Section Dependence in idiosyncratic components*

| Variable | Sample period | CD test (lag=0) | | CD test (lag=1) | | CD test (lag=2) | |
|---|---|---|---|---|---|---|---|
| | | Levels | First-differences | Levels | First-differences | Levels | First-difference |
| GDP | 1988-2003 | 1.46 | 2.94*** | 3.13*** | 3.24*** | 2.80*** | 2.69*** |
| Labor | 1988-2003 | -1.74 | -1.03 | -0.31 | -0.40 | -0.58 | -1.05 |
| Private Capital | 1988-2003 | -1.85 | 2.67*** | -1.85 | 2.26** | -1.60 | 1.78 |
| Public Capital | 1988-2003 | 0.49 | -1.42 | -1.12 | -1.50 | -0.87 | -1.05 |

Note: The panel consists of 29 regions with annual data of 16 years. Each idiosyncratic component is obtained from the decomposition of each corresponding variable at the region level in the natural logarithmic forms. *** and ** denote statistical significance at the 1 and 5 percent level. The CD statistic has an asymptotic standard normal distribution under the null hypothesis of no cross-section dependence. The ADF test equation for the variables both in levels and in first differences contains region-specific intercepts, linear time trends and three cases for lag orders of zero, one and two for the respective idiosyncratic component. The tests are carried out using the MATLAB procedures written by the author.

Table 13 above clearly indicates strong cross-section independence for each idiosyncratic component of each corresponding variable of labor and public capital in both levels and first-differences when the lag order equals zero, one and two respectively, which provides a significant contrast with Table 11, where the two variables of labor and public capital are both subject to strong cross-section dependence in both levels and first-differences when the lag order equals zero, one and two respectively. Therefore, the single factor model works pretty well for the two variables. For the idiosyncratic component of private capital, no cross-section dependence is found when it is in levels. When the idiosyncratic

component is in first differences, the CD test finds no cross-section dependence for the lag order of two, but finds cross-section dependence for the lag order of zero and one. Therefore, the two-factor model also performs pretty well for the variable of private capital. For the idiosyncratic component of GDP, the results are mixed. Although the CD test finds no cross-section dependence for its idiosyncratic component in levels when the lag order equals zero, the cross-section dependence cannot be statistically rejected in other scenarios. Despite the fact, the test statistics for the idiosyncratic component of GDP is much smaller than the counterparts for GDP, indicating that the single factor model does work for the variable of GDP to some extent. Therefore, considering the fact that both the single factor model and the two-factor model work pretty well for their corresponding variables as a whole, they are thus selected as the main models to be employed here[53].

After the factor components and the idiosyncratic components are obtained for each variable, the augmented Dickey-Fuller (ADF) test (a standard unit root test for time series) is conducted on the common factors and the Im-Pesaran-Shin (2003) test (a traditional panel unit root tests that assume cross-section independence) is applied to the idiosyncratic components, which leads to the second step of the procedure. Summarized results of the augmented Dickey-Fuller (ADF) test conducted on the common factors of the four variables in both levels and first differences are given below.

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[53]It should be noted that the selection of the single factor model to the GDP variable is also supported by the BIC3 criteria proposed by Bai and Ng (2002), which is also the best choice based on the existing methods.

| Common Factors | Sample period | ADF test (lag=0) | | ADF test (lag=1) | | Degree of Integration |
|---|---|---|---|---|---|---|
| | | Levels | First-differences | Levels | First-differences | |
| GDP-F1 | 1988-2003 | 0.51 | -2.38** | -1.17 | -3.39*** | I(1) |
| Labor-F1 | 1988-2003 | -1.34 | -4.20*** | -1.68* | -2.90*** | I(1) |
| Private Capital-F1 | 1988-2003 | 2.23 | -0.92 | 0.55 | -2.37** | I(1) |
| Private Capital-F2 | 1988-2003 | -0.86 | -1.35* | -2.49** | -1.45* | I(1) |
| Public Capital-F1 | 1988-2003 | -0.36 | -1.05 | -1.95** | -1.13 | I(2)[54] |

Note: The time series consist of 5 single common factors corresponding to the 4 variables respectively with annual data of 16 years. ***, **, * denote statistical significance at the 1, 5, 10 percent level respectively. The table gives the standardized test statistic for the ADF test. The test statistics have an asymptotic t distribution under the null hypothesis of nonstationarity. The test equation for each common factor in both levels and first differences contains a nonzero drift and two cases for lag orders of zero and one for the respective common factor. The lag order for each ADF test is determined based on the method proposed by Ng and Perron (2001), with the optimal value of zero for each test. The ADF results when the lag order equals one are also given as references. The tests are carried out using the Stata built-in module *"dfuller"*.

The table above indicates that the two single common factors corresponding to the two variables of GDP and labor are integrated of the same order one. For the two common factors of private capital, the ADF tests show that both of them may be integrated of the same order one although the conclusion is not strongly supported by the test results. For the single common factor of public capital, the ADF tests show that it is integrated of

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[54]The test statistic for the single common factor of the variable of public capital in second differences is statistically significant at 1% level when the lag order is zero and is statistically significant at 10% level when the lag order is one, with corresponding values of -3.11 and -1.67 respectively.

order two. Therefore, the five common factors of the four variables are not integrated of the same order.

Next, the Im-Pesaran-Shin (2003) test, one of the popular panel unit root tests that assumes cross-section independence in heterogeneous panels, is used to check the nonstationarity of the two idiosyncratic components of labor and public capital in both levels and first differences. Meanwhile, the Im-Pesaran-Shin (2003) test is also conduced on the two idiosyncratic components of GDP and private capital in levels. However, since the two idiosyncratic components of GDP and private capital in first differences are subject to cross-section dependence based on the results of the CD tests from Table 13, the Pesaran's CIPS (2005) test that considers cross-section dependence is applied to the idiosyncratic components of GDP and private capital in first differences. Summarized results of the panel unit root tests conducted on the four idiosyncratic components in both levels and first differences are given below, which strongly suggests that the idiosyncratic components of GDP, labor, private capital and public capital are integrated of the same order one.

*Table 15: Panel Unit Root Tests for Idiosyncratic Components*

| Idiosyncratic Components | Sample period | Im-Pesaran-Shin test (lag=1) | | Im-Pesaran-Shin test (lag=2) | | Degree of Integration |
|---|---|---|---|---|---|---|
| | | Levels | First-differences | Levels | First-differences | |
| GDP | 1988-2003 | 1.94 | -3.92*** | 0.67 | -2.84*** | I(1) |
| Labor | 1988-2003 | -1.21 | -8.29*** | 1.42 | -2.85*** | I(1) |
| Private Capital | 1988-2003 | 2.44 | -3.28*** | 5.71 | -1.46* | I(1) |
| Public Capital | 1988-2003 | -0.76 | -3.51*** | -0.63 | -1.49* | I(1) |

Note: The panel consists of 29 regions with annual data of 16 years. Each idiosyncratic component is obtained from the decomposition of each corresponding variable at the region level in the natural logarithmic forms. *** and * denote statistical significance at the 1 and 10 percent level. The table gives the standardized t-bar statistic for the Im-Pesaran-Shin (2003) test. This statistic has an asymptotic standard normal distribution under the null hypothesis of nonstationarity. The test equation for the idiosyncratic components in levels contains region-specific intercepts, linear time trends and two cases for lag orders of one and two for the respective idiosyncratic component. The test equation for the idiosyncratic components in first differences contains region-specific intercepts and two cases for lag orders of one and two for the respective idiosyncratic component. The Pesaran's CIPS (2005) test is applied to the idiosyncratic components of GDP and private capital in first differences with standardized t-bar statistics provided. The test statistic has an asymptotic standard normal distribution under the null hypothesis of nonstationarity. The specifications of the test equation are the same as those of the Im-Pesaran-Shin (2003) test. The tests are carried out using the Stata built-in modules *"ipshin"* and *"pescadf"*.

The third step of the testing procedure is to conduct cointegration tests for common factors and idiosyncratic components respectively. As to the five time series common factors, it has been unnecessary to conduct any cointegration test for them, since they are not integrated of the same order. However, considering the fact that the ADF test for the single common factor of public capital may give inaccurate testing results, the two-step testing procedure proposed by Engle and Granger (1987) is used to test the null hypothesis of cointegration among the five common factors assuming that they are integrated of the same order one. The testing results show that the five common factors are not cointegrated.

As to the idiosyncratic components of the four variables, a panel cointegration test is necessary since they are integrated of the same order one. Because the four idiosyncratic components in levels are constructed in such a way that they are not subject to cross-section dependence, a standard panel cointegration test that assumes cross-section independence is proper for them. More importantly, it should be noted that the results of the CD tests in Table 13 also confirm the fact that the four idiosyncratic components in levels are not subject to cross-section dependence[55]. Therefore, the panel cointegration tests, which are proposed by Pedroni (1999) with the null hypothesis of no cointegration and assume cross-section independence, are applied to check the co-integration among the four idiosyncratic components for its popularity and flexibility in specification. Although Pedroni (1999) constructs seven alternative panel cointegration statistics, the results of the two parametric tests are given below. Both tests reject the null hypothesis of no cointegration at the significance level of 1%.

*Table 16: Panel Cointegration Tests for Idiosyncratic Components*

| Test types | Null hypothesis | Alternative hypothesis | Test statistic |
|---|---|---|---|
| **Panel t-statistic** | $H_0$: $\eta_i$=1 for all i | $H_1$: $\eta_i$=$\eta$<1 for all i | -4.07*** |
| **Group t-statistic** | $H_0$: $\eta_i$=1 for all i | $H_1$: $\eta_i$<1 for all i | -4.92*** |

Note: The panel consists of 29 regions with annual data of 16 years. Each idiosyncratic component is obtained from the decomposition of each corresponding variable at the region level in the natural logarithmic forms. *** denotes statistical significance at the 1 percent level. The table gives the standardized t-statistics for the two parametric coinegration tests proposed by Pedroni (1999). Both

[55]The idiosyncratic component of GDP may be still subject to cross-section dependence to some extent, but it cannot deny the fact that the issue of cross-section dependence has been weakened greatly for the four idiosyncratic components.

test statistics have an asymptotic standard normal distribution under the null hypothesis of no cointegration. The tests are carried out using the RATS code developed by Pedroni (1999).

Based on the three steps of testing procedure for panel cointegration above, the four variables of GDP, labor, private capital and public capital are decomposed to five common factors and four idiosyncratic components, where the five common factors are not cointegrated but the four idiosyncratic components are cointegrated. More importantly, since the idiosyncratic component of GDP and the idiosyncratic components of labor, private capital and public capital are cointegrated, the variable of GDP and the variables of labor, private capital and public capital are also cointegrated. Therefore, there is strong evidence for a long run relationship between the variable of GDP and the other variables of labor, private capital and public capital in the research.

## 6.1.3 Panel Estimate of the Cointegration Vector

In the last two subsections, the panel variables of GDP, labor, private capital and public capital are found to be integrated of the same order one. Meanwhile, the four variables are also cointegrated, which means that there exists a long-term equilibrium relationship among the four variables of GDP, labor, private capital and public capital. The main purpose of this subsection is then to estimate what the specific cointegration vector is or what the long-term equilibrium relationship might be in the research.

The between-dimension group mean panel Fully Modified Ordinary Least Square (FMOLS) method proposed by Pedroni (2000) is used to estimate the cointegration vector. As mentioned before, this estimator can account for the endogeneity of the

regressors and also for serial correlation of the residuals in panel cointegrated models in addition to the allowance for heterogeneity among individual cross-section panel members. The table below reports estimates of the cointegration vector based on Pedroni's (2000) group-mean panel FMOLS estimator.

*Table 17: Panel Estimate of the Cointegration Vector*

| Geographic Scale | Elasticity of Output with respect to | | |
|---|---|---|---|
| | Labor Input | Private Capital | Public Capital |
| **National Level** | 0.32*** (-22.25) | 0.54*** (-25.01) | 0.15*** (-67.86) |
| **Eastern Mega-Region** | 0.29*** (-12.68) | 0.61*** (-12.03) | 0.12*** (-31.70) |
| **Central Mega-Region** | 0.21*** (-17.14) | 0.55*** (-17.33) | 0.19*** (-44.18) |
| **Western Mega-Region** | 0.48*** (-8.66) | 0.42*** (-14.49) | 0.16*** (-43.52) |

Note: The panel consists of 29 regions with annual data of 17 years (1987-2003) in China. The definition for each mega-region is consistent with the one defined before. All variables at the region level are in the natural logarithmic forms. *** denotes statistical significance at the 1 percent level and t-values are in parentheses. Each of the cointegration vector is estimated using the RATS code developed by Pedroni (2000).

For the estimate of the cointegration vector at the national level in China, the table above strongly suggests that the estimates of the three parameters of the production function are statistically significant at the 1% level. Moreover, all three estimates of output elasticities have expected sign and reasonable quantities. The estimates of the elasticities of output in regard to labor, private capital and public capital suggest that the production function exhibits constant returns to the three inputs. The panel results show that the point estimate of the elasticity of output in regard to public capital is about 0.15, which is statistically significant at the 1% level. Therefore, the finding of the positive and statistically

significant estimated elasticity of output regarding public capital indicates that public capital is productive in China across 29 regions for the period 1987-2003. In other words, public capital does have positive effects on regional economic output in China from 1987 to 2003. Finally, the panel results also suggest that the productive effect of public capital is only moderate compared with the other two inputs of private capital and labor. Among the three inputs of labor, private capital and public capital in the context of China, private capital is the most productive with the output elasticity of 0.54, labor (including human capital) is the less productive with the output elasticity of 0.32, and public capital is the least productive with the output elasticity of 0.15.

For the cointegration vectors at the three mega-regions in China, the table above also gives their estimates respectively. Similar to the estimates at the national level, estimates of the three parameters of the production function at each mega-region are also statistically significant at the 1% level with expected sign and reasonable quantities. Meanwhile, the productive effect of public capital is also the smallest compared with the other two inputs of private capital and labor at the three mega-regions. However, the three mega-regions are different in the extent to which each factor input is productive. The point estimates of the elasticity of output regarding public capital is 0.12, 0.19 and 0.16 for the eastern, central and western mega-regions respectively, which means that the productive effect of public capital is largest in the central mega-region and smallest in the eastern mega-region among the three mega-regions. Moreover, private capital is the most productive in the eastern mega-region, followed by the central mega-region and western mega-region sequentially. For the labor input, the factor is the most productive in the

157

western mega-region, followed by the eastern mega-region and the central mega-region sequentially. Finally, both of the eastern and central mega-regions have the highest elasticity of output in private capital, and then followed by labor and public capital. In contrast, the western mega-region has the highest elasticity of output in labor, and then followed by private capital and public capital.

## 6.1.4 Spillover Effects of Public Capital

In the previous sections, the productive effects of public capital in China across 29 regions for the period 1987-2003 have been checked and verified. Here, the spillover effects of public capital are further tested by adding a spillovers variable to the original log-linear Cobb-Douglas model, where the spillovers variable is defined as the average of the public capitals for a region's first-order neighboring regions. A nonstationary panel analytical framework, which includes the three-step procedure of panel unit root tests, panel cointegration tests and panel estimate of the cointegration vector, is then employed to the new panel Cobb-Douglas production function model for testing any spillover effects of public capital in China. The testing results for the new spillovers variable (S) are given below while the results for other variables can be found in the previous subsections.

For the panel unit root test, the CD diagnostic test for cross-section dependence in panels proposed by Pesaran (2004) is used to check whether the cross-section dependence is present for the spillover variable (in the natural logarithm) with results given below.

158

*Table 18: CD Diagnostic Tests for Cross Section Dependence in Spillovers*

| Variable | Sample period | CD test (lag=1) | |
| --- | --- | --- | --- |
| | | **Levels** | **First-differences** |
| **Spillovers** | 1987-2003 | 55.73*** | 52.36*** |

Note: The variable consists of 29 regions with annual data of 17 years in China. *** denotes statistical significance at the 1 percent level. The CD statistic has an asymptotic standard normal distribution under the null hypothesis of no cross-section dependence.

Table 18 shows that strong cross-section dependence exists for the spillovers variable (S) and the panel unit root test that considers cross section dependence among units in the panel should be used to check the nonstationarity of the spillovers variable. The results of the panel unit root tests proposed by Pesaran (2005) are given below.

*Table 19: Panel Unit Root Tests for Spillovers*

| Variable | Sample period | Pesaran's CIPS test (lag=1) | | Degree of Integration |
| --- | --- | --- | --- | --- |
| | | **Levels** | **First-differences** | |
| **Spillovers** | 1987-2003 | 0.10 | -1.34* | I(1) |

Note: The variable consists of 29 regions with annual data of 17 years in China. * denotes statistical significance at the 10 percent level. The table gives the standardized t-bar statistic for the Pesaran's CIPS (2005) test. The test statistic has an asymptotic standard normal distribution under the null hypothesis of nonstationarity.

From the table above, the Pesaran's CIPS (2005) test suggests that the spillovers variable is nonstationary in levels, but then become stationary in first differences. Based on the results of Table 12 and Table 19, it seems that the five variables of GDP, labor, private capital, public capital, and spillovers are all integrated of the same order one.

For the panel cointegration test, the three-step sequential strategy for testing for no-cointegration proposed by Gengenbach, Palm and Urbain (2006) is also used here to conduct the panel cointegration test for the five variables in the dissertation. First, as what have been done before, the nonstationary variable of spillovers is decomposed to the two parts of common factors and idiosyncratic components by conducting a PANIC analysis as suggested by Bai and Ng (2004), where a single factor model is applied to the spillovers variable. Results of the CD test (Pesaran, 2004) for cross-section dependence in the idiosyncratic component part of the spillovers variable are given below.

*Table 20: CD Diagnostic Tests for Cross Section Dependence in idiosyncratic component*

| Variable | Sample period | CD test (lag=2) | |
| --- | --- | --- | --- |
| | | Levels | First-differences |
| Spillovers | 1988-2003 | -1.73* | -1.34 |

Note: The variable consists of 29 regions with annual data of 16 years. The idiosyncratic component is obtained from the decomposition of the corresponding variable at the region level in the natural logarithmic forms. * denotes statistical significance at the 10 percent level. The CD statistic has an asymptotic standard normal distribution under the null hypothesis of no cross-section dependence.

The table above indicates cross-sectional independence for the idiosyncratic component of the spillovers variable in first-differences and slight cross-sectional dependence for the idiosyncratic component of the spillovers variable in levels, which provides a significant contrast with Table 18, where the spillovers variable is subject to strong cross-section dependence in both levels and first-differences.

Second, the Im-Pesaran-Shin (2003) test is used to check the nonstationarity of the idiosyncratic component of the spillovers variable in both levels and first differences with the results given below.

*Table 21: Panel Unit Root Tests for Idiosyncratic Component*

| Idiosyncratic Components | Sample period | Im-Pesaran-Shin test (lag=1) | | Degree of Integration |
| --- | --- | --- | --- | --- |
| | | Levels | First-differences | |
| Spillovers | 1988-2003 | 0.64 | -1.97** | I(1) |

Note: The variable consists of 29 regions with annual data of 16 years. The idiosyncratic component is obtained from the decomposition of the corresponding variable at the region level in the natural logarithmic forms. ** denotes statistical significance at the 5 percent level. The table gives the standardized t-bar statistic for the Im-Pesaran-Shin (2003) test. This statistic has an asymptotic standard normal distribution under the null hypothesis of nonstationarity.

The table above clearly suggests that the idiosyncratic component of spillovers is integrated of the same order one as that of GDP, labor, private capital and public capital in Table 15. Moreover, since the five common factors of the four variables of GDP, labor, private capital and public capital are not integrated of the same order, it is unnecessary to conduct any time series unit root test for the common factor of the spillovers variable.

The third step of the panel cointegration testing procedure is to conduct cointegration test for idiosyncratic components of the five variables of GDP, labor, private capital, public capital and spillovers. Then, the panel cointegration tests, which are proposed by Pedroni (1999) with the null hypothesis of no cointegration and assume cross-section independence, are applied to check the co-integration among the five idiosyncratic components. Although Pedroni (1999) constructs seven alternative panel cointegration

statistics, the results of the two parametric tests are given below. It seems that both tests reject the null hypothesis of no cointegration at the significance level of 1%.

*Table 22: Panel Cointegration Tests for Idiosyncratic Components*

| Test types | Test statistic |
|---|---|
| **Panel t-statistic** | -6.09*** |
| **Group t-statistic** | -5.00 *** |

Note: The panel consists of 29 regions with annual data of 16 years. Each idiosyncratic component is obtained from the decomposition of each corresponding variable at the region level in the natural logarithmic forms. *** denotes statistical significance at the 1 percent level. The table gives the standardized t-statistics for the two parametric coinegration tests proposed by Pedroni (1999). Both test statistics have an asymptotic standard normal distribution under the null hypothesis of no cointegration.

Based on the three steps of testing procedure for panel cointegration above, it shows that the five idiosyncratic components of GDP, labor, private capital, public capital and spillovers are cointegrated, which means that the variable of GDP and the variables of labor, private capital, public capital and spillovers are also cointegrated. Therefore, there is strong evidence for a long run relationship between the variable of GDP and the other variables of labor, private capital, public capital and spillovers in the dissertation.

For the part of the panel estimate of the cointegration vector, its main purpose is to estimate what the specific cointegration vector is or what the long-term equilibrium relationship might be among the five variables in the research. The between-dimension group mean panel Fully Modified Ordinary Least Square (FMOLS) method proposed by Pedroni (2000) is used to estimate the cointegration vector. The table below reports

estimates of the cointegration vector based on Pedroni's (2000) group-mean panel FMOLS estimator.

*Table 23: Panel Estimate of the Cointegration Vector*

| Geographic Scale | Elasticity of Output with respect to | | | |
|---|---|---|---|---|
| | Labor Input | Private Capital | Public Capital | First-Order Neighboring Public Capital (Spillovers) |
| **National Level (Model 2)** | 0.12*** (-35.65) | 0.52*** (-25.31) | 0.09*** (-67.71) | 0.11*** (-64.51) |
| **National Level (Model 1)** | 0.32*** (-22.25) | 0.54*** (-25.01) | 0.15*** (-67.86) | N/A |

Note: The panel consists of 29 regions with annual data of 17 years (1987-2003) in China. All variables at the region level are in the natural logarithmic forms. *** denotes statistical significance at the 1 percent level and t-values are in parentheses. Model 1 refers to the original model without the consideration of the spillover effects of public capital and Model 2 refers to the current model taking the spillover effects of public capital into account. N/A means not applicable.

For the estimate of the cointegration vector at the national level in China, the table above strongly suggests that the estimates of the four parameters of the production function are statistically significant at the 1% level. Meanwhile, all four estimates of output elasticities have expected sign and reasonable quantities. The estimates of the elasticities of output in regard to labor, private capital, public capital and spillovers suggest that the production function exhibits diminishing returns to scale. The panel results show that the point estimate of the elasticity of output in regard to spillovers is about 0.11, which is even larger than that of output regarding public capital (0.09). Therefore, it seems that the regional spillover effects of public capital in China are positive and large, which is even larger than the productive effects of public capital of its own. Moreover, the panel results

also suggest that the productive and spillover effects of public capital are only moderate compared with the other two inputs of private capital and labor. Finally, both of the results form model 1 and model 2 suggest that private capital is the most productive among these productive factors although the productive and spillover effects of public capital are also positive and significant.

## 6.2 A Panel Granger Causality Test of Infrastructure and Productivity in China

Granger causality test has become a popular and useful method for investigating the nature of the causal relationship between two variables for several decades. Although it was originally developed and applied for time series pairs, Granger causality test has been extended to the context of panel data with recent theoretical developments (Holtz-Eakin, Newey, and Rosen, 1988; Arellano and Bond, 1991; Hurlin and Venet, 2001; Hurlin, 2004). In this section, the causal relationship between infrastructure and productivity in China is studied using the panel Granger causality test proposed by Hurlin (2004).

Specifically, public capital is used as a proxy for infrastructure and GDP is used as a proxy for productivity. Both of the two variables (public capital and GDP) have the same definitions as those employed in the section 6.1 and are expressed in natural logarithmic forms. As what have been demonstrated in section 6.1, the variables of public capital and GDP are both nonstationary in levels but become stationary in first differences. Therefore, the panel Granger causality test, which tests the causal relationship between

164

two stationary panel variables, is conducted on the two variables in first differences for 29 regions in China spanning 16 years for the period 1988 - 2003 to test any possible causal relationship between them. The testing results for the panel Granger causality test are given below.

*Table 24: Panel Causality Test for Public Capital and Output*

|  | Causality from Public Capital to Output | | | Causality from Output to Public Capital | | |
|---|---|---|---|---|---|---|
|  | Lag=1 | Lag=2 | Lag=3 | Lag=1 | Lag=2 | Lag=3 |
| **National Level** | 1.31 | 2.98*** | 13.23*** | 7.07*** | 13.05*** | 14.77*** |
| **Eastern Mega-Region** | 1.58 | 2.81*** | 15.27*** | 11.28*** | 8.44*** | 9.56*** |
| **Central Mega-Region** | -0.84 | -0.62 | 3.05*** | 2.41** | 5.30*** | 6.69*** |
| **Western Mega-Region** | 1.56 | 2.98*** | 5.51*** | -0.34 | 8.68*** | 9.16*** |

Note: The panel consists of 29 regions with annual data of 16 years (1988-2003) in China. The definition for each mega-region is consistent with the one defined before. The two variables of public capital and GDP at the region level are in the natural logarithmic forms and in first differences. ***, ** denotes statistical significance at the 1, 5 percent level. The table gives the approximated standardized statistics for the Granger non causality hypothesis proposed by Hurlin (2004). The test statistic has an asymptotic standard normal distribution under the null hypothesis of no causality relationship from public capital to output for any region in the panel or under the null hypothesis of no causality relationship from output to public capital for any region in the panel. The tests are carried out using both the Stata module "*gcause*"developed by Patrick (2002) and MATLAB codes programmed by the author.

Generally speaking, the table above shows that there exist strong causal relationships both from public capital to output and from output to public capital in China, which is especially significant when the lag order is higher. This kind of bilateral causal

relationship between public capital and output holds at both the national level and the mega-region level in China. However, there are some obvious differences between the causal relationship from public capital to output and from output to public capital. For the causality test from public capital to output, the null hypothesis, of no causality relationship from public capital to output, cannot be rejected even at the significance level of 10% when the lag order is one, although the null hypothesis is rejected when the lag order is two or three. In contrast, for the causality test from output to public capital, the null hypothesis, of no causality relationship from output to public capital, is strongly rejected in all scenarios where the lag order is one, two and three. This kind of difference in causality relationship between public capital and output also holds at both the national and the mega-region levels in China. Therefore, compared with the causal relationship from output to public capital, the causality relationship from public capital to output is more sensitive to the the selection of lag order, which indicates that public capital may influence output during a longer time horizon than output does public capital in China.

## 6.3 Summary

The research presents two empirical studies of the relationship between public capital and regional productivity using a sample of 29 regions of China for a 17-year period of 1987-2003. For one thing, a three-step nonstationary panel analytical procedure is conducted to investigate whether public capital is productive in China. For the first step, the panel unit root test proposed by Pesaran (2005) strongly suggests that the four regional variables of GDP, labor, private capital and public capital are all integrated of the same order one (i.e.,

nonstationary in levels but stationary in first differences). For the second step, a PANIC analysis proposed by Bai and Ng (2004) is conducted to decompose each nonstationary variable into two parts of common factors and idiosyncratic components. The fact that the four idiosyncratic components are found to be integrated of the same order one and also cointegrated suggests that the four variables of GDP, labor, private capital and public capital are cointegrated as well. For the third step, the panel estimation of the cointegration vector shows that public capital is productive in China across 29 regions from 1987 to 2003, with a moderate estimated output elasticity of 0.15 compared with that for private capital (0.54) and labor (0.32). Moreover, among the eastern, central and western mega-regions in China, the productive effect of public capital is largest in the central mega-region (0.19) and smallest in the eastern mega-region (0.12). Finally, the spillover effects of public capital in China are positive and significant, which is even larger than the productive effects of public capital on its own.

For another, a panel Granger causality test proposed by Hurlin (2004) is conducted to investigate the nature of the causal relationship between public capital and economic output in China. The test results show that there exist strong causal relationships both from public capital to output and from output to public capital in China, which holds in both the national level and the mega-region level in China. Moreover, the test results also suggest that public capital may influence output during a longer time horizon than output does public capital in China.

# 7 Conclusions and Policy Implications

The dissertation contributes to the empirical literature on the macroeconomic effects of public infrastructure, especially in the context of China. Based on a comprehensive and critical review of the literature attempting to study the productive effects of public capital, the research presents two empirical studies on the relationship between public capital and regional productivity in China. This chapter summarizes the main findings and conclusions, discusses the related policy implications, and suggestions directions for future research.

## 7.1 Conclusions

The main works of the dissertation can be divided into the following two aspects. For one thing, some general issues on the relationship between public infrastructure and economic productivity are critically reviewed and fully discussed. For another, the regional macroeconomic effects of public infrastructure in the context of China are empirically studied using the two newly-developed approaches of nonstationary panel technique and panel Granger causality test, with the main purpose to get some key insights into the specific relationship between public infrastructure and economic productivity in China.

- **Public Infrastructure and Economic Productivity**

The definition of public infrastructure used in the dissertation is a narrow one in nature, which mainly includes services from public utilities, public works and other transportation sectors (World Bank, 1994). Meanwhile, the research also emphasizes the characteristics of infrastructure as a kind of capital[56]. The main characteristics of infrastructure include low mobility, substantial initial investments, low marginal cost of adding an extra user, external economy, natural monopoly and coexistence of public and private ownership. The important economic growth theories related to infrastructure include theories of development economics, neoclassical growth theory and endogenous growth theory, all of which confirm the important effects of infrastructure on economic growth and development.

Although it has been generally accepted that public infrastructure can influence economic productivity through a variety of mechanisms, there have been great controversies in the literature that attempts to measure the productive effects of public infrastructure empirically. The production function approach, which estimates the output elasticity of public capital in an extended Cobb-Douglas production function with the inclusion of public capital, is one of the most widely used methods in the field. The studies using the production function approach generally give mixed results on the economic effects of public capital.

When the production function approach is employed in the context of time series data, it is generally subject to such econometric problems as specification issues, reverse causation, spurious correlation and nonstationarity. Among these weaknesses, the

[56]Public infrastructure and public capital are two interchangeable terms in the dissertation.

nonstationarity issue is the most problematic and controversial. The traditional first-differencing method for handling nonstationarity is severely criticized for the main reason that it can destroy any long-term relationship in the time series and thus could yield implausible estimates of the coefficients. Therefore, more and more researchers believe that researchers should not only examine the extent to which the time series variables are nonstationary, but also whether they grow together over time and converge to certain long-run relationship (i.e. whether they are cointegrated). However, the cointegration tests in the context of time series data generally have lower power, which is particular problematic for small samples (Kamps, 2004; Destefanis, 2005). Since the sample periods for most empirical studies on the economic effects of public capital are only several decades, many researchers believe that "one way to increase the power of unit root tests and tests for co-integration is to make use of the cross-section dimension of the data in addition to the time-series dimension" (Kamps, 2004: 45), which naturally leads to the wide application of panel data.

When the approach is employed in the context of panel data, the nonstationarity issue can be remedied to a great extent. In particular, some researchers, which employ the newly-developed nonstationary panel techniques to estimate the output elasticity of public capital within the framework of the Cobb-Douglas production function, find positive effects of public capital on economic productivity. However, these studies are still subject to some weaknesses. One of the most severe problems is that both the panel unit root tests and panel cointegration tests employed by those researchers assume cross-sectional independence across units in the panel. This assumption is really very restricted and

unrealistic since it is very common for macro time series to exhibit significant cross-sectional correlation among the countries in the panel, which are much popular in the regional-level panel data studies. Fortunately, with the rapid developments in nonstationary panel techniques, new panel unit root tests and panel cointegration tests that assume cross-sectional dependence have emerged, which has made it possible to investigate the economic effects of public capital using the newly-developed techniques within the framework of production function model.

- **Public Infrastructure and Regional Productivity in China**

The infrastructure development in China has been extraordinarily rapid with great achievements in the last three decades, which also outperformed most other lower middle income countries in the world. Although infrastructure investments in China increased rapidly from 1985 to 2007, the distribution of these investments among different regions and mega-regions in China is quite unbalanced. However, although there had been an obvious regional disparity in the infrastructure investments among regions from 1986 to 1998, the situation has been reversed since 1999. In particular, the undeveloped regions and mega-regions in China have received more and more public infrastructure investments in recent years.

The rapid growth of public infrastructure in China can be explained from the two aspects of institutional changes and policy stimulus. Some important institutional changes conductive to infrastructure development in China include reform and opening-up strategy in China, streamlining central-local fiscal and tax relations, diversification of

mechanisms for financing infrastructure, and China's great western development strategy. Some important policy stimuli for the rapid development of transportation and telecommunications infrastructure in China include lowered tax rates, preferential terms on bank loans and credits, and preferential policies for collecting or attracting investment funds for infrastructure constructions in China.

Using a panel dataset covering 29 regions of China over the period of 1987-2003, the dissertation presents two empirical studies of the relationship between public capital and regional productivity in China. Since the official data on the public infrastructure capital stocks for China from 1987 to 2003 are nonexistent, one contribution of the dissertation is a methodology to estimate the variable using the perpetual inventory method. For the first study, a three-step nonstationary panel analytical procedure is conducted to investigate the macroeconomic effects of public capital in China under the aggregate Cobb-Douglas production function framework. Another important contribution of the dissertation is that no research of this kind has ever been conducted to investigate the productive effects of public capital as the analytical procedure and methodologies used in the research.

For the first step, the panel unit root test proposed by Pesaran (2005) that assumes cross-section dependence strongly suggests that the four regional variables of GDP, labor, private capital and public capital are all integrated of the same order one (i.e., nonstationary in levels but stationary in first differences). For the second step, since cross-section dependence exists in each of the four nonstationary variables under

investigation, traditional cointegration tests that assume cross-section independence could not be used directly. Thus a PANIC analysis proposed by Bai and Ng (2004) was conducted to decompose each nonstationary variable into the two parts of common factors and idiosyncratic components. Since the idiosyncratic components were constructed to be cross-sectional independent, then traditional cointegration tests can work on them. The fact that the four idiosyncratic components are found to be integrated of the same order one and also cointegrated suggests that the four variables of GDP, labor, private capital and public capital are cointegrated as well. For the third step, the cointegration vector is estimated based on Pedroni's (2000) between-dimension group mean panel fully modified OLS estimator, which can specially account for the endogeneity of the regressors and also for serial correlation of the residuals in panel cointegrated models.

The panel estimation of the cointegration vector shows that public capital is productive in China across 29 regions from 1987 to 2003, with a moderate estimated output elasticity of 0.15 compared with that for private capital (0.54) and labor (0.32). Meanwhile, the estimates of the elasticities of output in regard to labor, private capital and public capital suggest that the production function exhibits constant returns to the three inputs. Moreover, among the eastern, central and western mega-regions in China, the productive effect of public capital is largest in the central mega-region (0.19) and smallest in the eastern mega-region (0.12). The productive effect of public capital is also the smallest compared with the other two inputs of private capital and labor at the three mega-regions. Finally, both of the eastern and central mega-regions have the highest elasticity of output

in private capital, and then followed by labor and public capital. In contrast, the western mega-region has the highest elasticity of output in labor, and then followed by private capital and public capital.

The first study also attempts to test for the spillover effects of public capital by adding a spillovers variable to the original log-linear Cobb-Douglas model, where the spillovers variable is defined as the average of the public capital for a region's first-order neighboring regions. It shows that the point estimate of the elasticity of output in regard to spillovers is about 0.11, which is even larger than that of output regarding public capital (0.09). Therefore, the regional spillover effects of public capital in China from 1987 to 2003 are positive and large, even larger than the productive effects of public capital on its own.

For the second study, a panel Granger causality test proposed by Hurlin (2004) is conducted to investigate the nature of the possible causal relationship between public capital and economic output in China. The test results show that there exists a strong causal relationships both from public capital to output and from output to public capital in China, which holds at both the national level and the mega-region level in China. Moreover, the test results also suggest that public capital may influence output during a longer time horizon than output does on public capital in China.

## 7.2 Policy Implications

The dissertation, which attempts to carefully study the macroeconomic effects of pubic infrastructure in China for the period of 1987-2003, produces significant policy implications for policy makers in China as well as the other countries in the world.

First, the finding of the research that public capital does have a significant and positive impact on regional economic productivity in China confirms the validity and success of public investment-induced economic growth in China, the largest developing country and emergent economy in the world. More importantly, the research has provided adequate theoretical and empirical justification for those policy initiatives aiming to promote economic growth and development through investing in the infrastructure sector. The central and local government in China should adopt various policy stimuli to promote investment in public infrastructure, which will then have positive effects on economic productivity and growth in China, especially in the less developed regions of the country. Moreover, since the institutional environment for infrastructure investment and development also plays an important role for the rapid development of infrastructure in China, Chinese governments of different levels should also continue advancing any institutional reform and change that is conductive to long-term infrastructure development in China.

Second, the finding of the research that public capital may influence output during a longer time horizon than output does public capital in China also has important policy implications. When formulating and implementing any infrastructure investment policy

aiming to promote regional economic productivity and growth, policy makers in China should fully understand that a time lag may exist for the economic effect of public infrastructure. Therefore, the effectiveness of any infrastructure investment policy should be evaluated over a fairly longer time horizon.

Third, the dissertation also confirms the significant and positive effect of private capital and labor besides public capital on the regional productivity and growth in China. In particular, each productive effect of labor and private capital is even higher than that of public capital. At a national level, private capital has the largest productive effects with an output elasticity of 0.54. This seems to indicate then a strong FDI attraction program and entrepreneurship stimulus program to propel the growth of the private sector and then the regional productivity. Labor has the output elasticity of 0.32, which is also high and suggests that a strong education promotion policy to enhance the quality of human capital or labor. In contrast, public capital has the output elasticity of 0.15. It can be concluded that China's economic growth and development is still driven by the two factors of private capital and labor to a great extent. Therefore, policy makers in China should continue adopting those policies to foster the rapid growth of private capital investment and human capital (labor) in addition to public capital investment. A set of polices balanced but more weighted toward private capital and education/labor quality promotion among the three production factors are preferred. Moreover, considering the fact that the spillover effects of public capital are  positive and significant, regions with geographic proximities can take cooperative policies in stimulating the growth of public capital investments, which will have productive effects on the economy of these regions as a

whole. Actually, the central and local governments in China have gradually realized the importance of regional coordination and cooperation in promoting regional economic growth and development. Since 2009, the central government of China has approved 11 regional economic growth and development plans. Nowadays, regional cooperations and developments have been risen to a kind of national strategy in China and will play more and more important roles in promoting economic growth and development in China.

Fourth, the finding of the dissertation that the productive effects of private capital, labor and public capital are different in magnitude for the three mega-regions in China also has significant policy implications. For the eastern and central mega-regions, policies for the development of private investments should be given priority comparatively since its productive effect is the largest among the three production factors. For the western mega-region, policies for the development of human capital (labor) should be given priority since its productive effect is the largest among the three production factors.

Finally, although the research for the macroeconomic effects of public infrastructure is conducted in the context of China, its findings have important policy implications for policy makers in other countries besides China. As the largest developing country in the world, China has been one of the fastest-growing economies in the world in the last three decades. Those theoretical and empirical findings from the study in this dissertation of the relationship between public infrastructure and economic productivity in China should be enlightening to other countries in the world, especially those that hope to replicate China's success in their own countries.

## 7.3 Directions for Future Research

Future research should be conducted in the following areas. First, since the public capital stocks for China in empirical studies are estimated based on the investments in fixed assets for the sector of transportation, storage, postal and telecommunication services, other components of the infrastructure sector such as public utilities should be added to estimate the new public capital stocks for China when the related data are available. The research period should also be extended to cover a longer time horizon when more data are available in future. Meanwhile, how to determine a more reasonable depreciation rate for the estimation of infrastructure stocks in China also needs further research. Moreover, the spatial scale for this dissertation is the provincial level because the related data are only available at the provincial level in China. Although it appears to be the best choice that can be made now, it should be kept in mind that using the province as the spatial scale will surely mask many variances at the sub-provincial level in China. Further studies at the sub-provincial level for analysis should be undertaken once the data at the sub-provincial level in China are available. Finally, The spillovers variable, which is defined as the first-order neighboring public capital and added to the original log-linear Cobb-Douglas model to measure the spillover effects of public capital in the dissertation, can also be extended as the second or higher-order neighboring public capital.

Second, there are still some issues in the three-step nonstationary panel analytical procedure that need to be further examined. For one thing, some results for panel unit root tests and panel cross-section dependence tests in the research are not robust and may

depend on the selection of the time lag used. More effort is needed to fully investigate the nature of the unrobustness of the analysis. It should also be noted that the issue on the optimal selection of the time lag for panel unit root tests and panel cross-section dependence tests has not been resolved in this study or in the current literature. For another, as to the sequential strategy for panel cointegration test employed in the research, the PANIC analysis, proposed by Bai and Ng (2002), attempts to resolve the issue of the panel cross-sectional dependence, works pretty well for the three variables of labor, private capital and public capital but not so well for the GDP variable. More research is needed to ascertain the exact reason for the problem and an alternative method needs to be developed for solving the problem.

Third, for most empirical studies that use the production function approach to study the productive effects of public capital, the production function is generally assumed to be the Cobb-Douglas form. However, since a Cobb-Douglas production function strictly restricts the substitution elasticities of the production factors to be one, it is a very strict assumption and may not hold in reality. A translog function, which is a more general form of production function than a Cobb-Douglas function, can be chosen to replace the Cobb-Douglas function to access the macroeconomic effects of public infrastructure in China.

Fourth, the production function approach is only one of the econometric approaches for investigating economic effects of public capital. Some other approaches, which may include the cost function approach, the Vector Autoregressive (VAR) approach and the production frontier approach (also called Data Envelopment Analysis), can also be used

to study the macroeconomic effects of public infrastructure in China. The empirical findings, obtained from different approaches using the same data set, will provide a more comprehensive overview of the macroeconomic effects of public infrastructure in China and will surely tell us if the results converge or not.

Finally, some important research topics, such as the specific mechanisms through which public infrastructure influences regional economic productivity in China, the possible substitution or complementarity relationship between public capital and private capital in China are good supplements and extensions to the dissertation and should be conducted in future research.

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187

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