Public Infrastructure Investment and Economic Growth In China:

An Empirical Analysis Using VAR

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Abstract

The relationship between infrastructure investment and economic growth in China, one of the fastest growing countries in the last three decades in the world, has been an active field of study for a long period. The purpose of this paper is to investigate the role of public infrastructure investment on economic growth in China during the period 1978 to 2009 using econometrics tests, such as stationary tests, co-integration tests, Granger causality tests, as well as VAR models and VECM. Overall, the results indicate that total public infrastructure investment in China has a significant positive impact on economic growth in the long run. Besides, in all industries (mining, transportation, telecommunication, education and health care, etc) except agriculture, infrastructure investment has a positive contribution to overall economic growth. Moreover, each industry's infrastructure investment contributes positively to the corresponding industry. The experience of China seems to validate the conventional wisdom that suggests an active government involvement in the provision of public infrastructure so as to achieve sustainable economic growth.

Keywords: Infrastructure investment, economic growth, stationary test, co-integration test, vector auto-regression, vector error correction.

1. Introduction

In more than three decades of market-oriented reforms, China has sustained a remarkable average economic growth rate of 9.8% and the share of China's GDP in the world's total GDP has increased year by year and reached 9.5% at the end of 2010.[1] Also, the absolute poverty population has reduced from 250 million in 1978 to 15 million in 2007.[2] All this impressive economic performance attracts worldwide attention, especially after two serious economic crises, the Asia financial crisis in 1997 and the global subprime mortgage crisis in 2007. In the situation of these international financial crises and current worldwide economic recession, Chinese government took expansionary fiscal policy to sustain the high economic growth rate. Obviously, after international market demand slump in a financial crisis, large-scale fixed assets investment, most of which going into infrastructure construction, has replaced export and manufacturing as the primary power that pushed the fast-growing Chinese economy.

As suggested by Arthur and Steven (2003), infrastructure consists of basic physical and organizational structures needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function. Moreover, the World Bank (1994) defines infrastructure as public services (electricity, energy, and water facilities), public works (roads) and other transportation facilities (harbors and airports). Up to now, infrastructure has become a broad concept that includes not only highway, railway, airport, telecommunication, water, electricity, gas and other public facilities that is commonly known as the physical or hard infrastructure, but also education, science and technology, health, sports, culture and

[1] Chinese Statistic Bureau (2011).

[2] Chinese Statistic Bureau (2008).

other social programs that is defined as social or soft infrastructure.[3] As is commonly known infrastructure development is one of the crucial determinants of economic growth, especially in developing countries.

After the pioneering empirical work by Aschauer (1989), numerous empirical studies have been carried out to assess the impact of investment in infrastructure on economic growth. Aschauer (1989) finds that infrastructure investment has positive effect on economic growth. This conclusion has been debated for more than two decades with data from various Western countries (Gramlich, 1994; Romp and De Haan, 2007). Despite the numerous studies on this subject, there is no consensus on the real impact of infrastructure on growth as opposite views can still be found in the literature. The review of approximately 40 among the main papers on the impact of infrastructure on growth has allowed us to identify at least four potential causes to the wide variation of the results across studies. These causes pertain to the data used and to the empirical methods employed:

First, the type of public capital selected is restricted by the availability of economic data: core or non-core infrastructure, even the different combination of infrastructure categories (especially in the studies of China's situation). Core infrastructure includes roads, railways, airports and utilities such as sewerage and water facilities, while non-core infrastructure includes education, science and technology, health, sports, culture and other social programs. For example, Aschauer (1989) indicates that a 'core' infrastructure of streets, highways, airports, mass transit, sewers, water systems, etc. has most explanatory power for economic growth, while Zhang (2004) investigates the correlations between public physical capital investment (core), R&D capital investment (non-core) and economic growth and indicates that

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[3] Kumar (2004). "Infrastructure in India." The ICFAL Journal of infrastructure

these public investments have different positive effect on economic growth in different ways.

Second, the appropriate aggregation level for the selected variables needs to be decided with respect to the scale of the study (i.e., cross-national, national, regional, or project level). For instance, Sanchez-Robles(1998), Devarajan, Swaroop and Zou (1996) use cross-country data, Aschauer (1989), Lynde and Richmon (1992), Guo, Guo and Xia (2010) all use national time series data, while Evans and Karras (1994), Munnell (1990), Liu (2003), Liu (2002) use the regional panel data.

Third, the concept of infrastructure (stock or flow) also matters. For instance, Aschauer (1989), Lynde and Richmon (1992), Zhu (2004) assess the contribution of infrastructure capital stock to economic growth, while Morrison and Schwartz (1996), Gao and Li (2006) examine the impact of investment (flow) in infrastructure on economic growth.

Fourth is the selection of empirical estimation methods used. In the literature, three mainstream empirical test methods are commonly employed: Production Function Approach, Cost Function Approach, and Vector Auto-regression Approach (VAR). Production Function Approach was first used by Aschauer (1989a) and widely applied in many studies (e.g., Munnel, 1990, Liu, 2009). A major critique of this approach is the lack of treatment on the reverse causality that possibly directs from economic development to infrastructure investment (Gramlich,1994) and the inability to show how infrastructure investment stimulates the economic development.[4] Cost Function Approach, which is also widely used (e.g. Morrison & Schwartz, 1996; Bougheas, Demetriades and Mamuneas, 2000), can show whether infrastructure investment can contribute to economic development and how this effect

[4] Baird (2005).

is realized. A major critique of this approach is the availability of the public infrastructure price data and the difficulty in calculating the cost reduction. Vector Auto-regression Approach (VAR) offers a flexible framework in which the variables are treated symmetrically; each variable has an equation explaining its evolution based on its own lags and the lags of all the other variables in the model. Many studies have been conducted under this method (e.g. Tang, 2010; Guo, Guo and Xia, 2010).

The purpose of this paper is to investigate the impact of public infrastructure on economic growth in China from an insightful perspective. First, instead of using production function model and cost function model, this paper employs a VAR model to analyze time series statistical data from the 1978 to 2009. The reason for this is that the VAR approach is flexible in providing a uniform framework for handling infrastructure investment variables with the determinants of economic growth . In this paper, within this VAR framework, a restricted VAR model will be investigated through multiple steps of stationary test, co-integration analysis, Granger causality test, and vector error correction procedure.

Though there are some studies using VAR models to analyze this issue, they either have limited focus on a small part of infrastructure investment such as the transportation infrastructure investment (Guo, Guo and Xia, 2010), or test a smaller time period from 1994 to 2008 (Tang, 2010). Moreover, this paper uses five specifications of VAR models. The first one is a general model test, estimating the impact of total infrastructure investment on national GDP. The second one is a sectoral impact model, which estimates the effect of sectoral infrastructure investment on the national GDP. The rest are also sectoral impact models, however, they investigate the effect of sectoral infrastructure investment on their corresponding sectoral GDP.

The remainder of the paper is arranged as follows: section 2 briefly introduces infrastructure development and current situation in China; section 3 is a literature review; section 4 presents the theoretical framework and the model specification; section 5 describes the data, presents the empirical test and discusses the results; the last section concludes and offers some suggestions.

2. Infrastructure development and current situation in China

During the last half century, the economic development in China has experienced three periods. As pointed out by Liu (2003), they are Highly-central-planned period, Transformation period and Market-based period. From the article published by the National Bureau of Statistics of China (2009), we can get a rough understanding of the basic process of the development of China's infrastructure investment.[5]

In the central-planned period before the Reform and Opening up policy had been taken in the late 1970s, infrastructure in China experienced slow development stages, but the industrial investment growth is relatively fast. In the early 1950s, China was in extreme poverty. After three years of recovery, the first "five year plan" started. From then on, China underwent a large-scale economic construction, of which basic industries and infrastructure were an important composition. From 1954 to 1977, the total completed basic industries and infrastructure investment in capital construction was 299.6 billion Yuan with average annual growth rate of 8.7%.[6] However, at that time, the economic focus of the government was on heavy industry. Coal mining, oil, and electricity industries investment thus grew fast. Also, because of the influence of "the great leap forward" and "cultural revolution", the fundamental industry and infrastructure investment grew at the lowest average annual rate in the 30 years before

[5] China's 60 years basic industries and infrastructure construction has made brilliant achievements. China Statistic Bureau (2009).

[6] China Statistic Bureau (2009).

the reform and opening up policy.

At the beginning of the transformation period during 1978-1989, the scale of investment of the whole society was very small. Basic industry and infrastructure was still very weak. To change this situation, China devoted its limited funds to several key industries, such as agriculture, transportation, source of energy, education, health care, etc. During that period, the total investment of basic industries and infrastructure construction was 547.9 billion Yuan, with an average annual increase of 10.7%.[7] As the reform and opening up continued, the material production became continuously abundant and product supply was prosperous. The opening-up also facilitated the inflow of foreign direct investment (FDI) to the manufacturing sector. Cheap labor and better infrastructure both nourished the export-led growth strategy. However, unlike the seemingly unlimited supply of cheap labor, infrastructure failed to grow as fast as the economy, causing the so-called "bottleneck" problem.[8]

After 1990s, in order to realize the second step of strategic modernization target, the Chinese government outlined the "People's Republic of China's ten year national economic and social development planning and eighth five-year program", which proposed future development goal of agriculture, water conservation, energy, transportation, post and telecommunications, raw materials and other industries. During that period, investment in basic industries and in infrastructure grew fast. During 1990-2002, total investment in basic industries and infrastructure construction was 8.0249 trillion Yuan, with the average annual growth of 26%, much higher than the average annual rate of 15.3% during 1979-1989.[9]

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[7] China Statistic Bureau (2009).

[8] Liu (2003). "Studies on Promoting effect of Infrastructure Investment in Economic Growth"

[9] All the data used here come from China's 60 years basic industries and infrastructure construction has made brilliant achievements. China Statistic Bureau (2009).

During this period, Treasury funds played an outstanding role in basic industry and infrastructure investment. Since 1998, after Asia financial crisis, Chinese government intended to stimulate the domestic demand by an expansionary fiscal policy. About 660 billion Yuan of special Treasury bonds were issued during 1998-2002 for basic industry and infrastructure investment. These funds were mainly used in agriculture, water conservation, transportation, communication, urban infrastructure, urban and rural network reconstruction, the central reserve grain depot and other infrastructure projects. These capital investments, joined by private capital, formed the basis of rapid growth of investment in industry and infrastructure. During 1998-2002, total investment in basic industries and infrastructure construction was 7.3380 trillion Yuan, with the average annual growth of 13.1%. This investment spurred the growth of investment of the whole society, and also led the country smoothly out of difficult economic times.

During the year 2003-2008, Chinese government on one hand took measures to strengthen governmental investment in basic industry and the infrastructure construction, on the other hand, encouraged foreign and domestic private investment in the basic industries and infrastructure construction projects. This had again boosted China's basic industries and infrastructure and vastly improved people's living condition in urban and rural area. During 2003-2008, total investment in basic industries and infrastructure construction was 24.677 trillion Yuan, the average annual growth rate 24.5%[10]. Particularly, after the falling global demand had caused a decline in growth rate of China's export-led economy since 2008 global crisis, Chinese government has invested 4 trillion Yuan in infrastructure and public services to

[10] China's 60 years basic industries and infrastructure construction has made brilliant achievements. China Statistic Bureau (2009).

stimulate the economy and maintain a high growth rate.[11] The following chart shows the composition of this investment. From it we can see clearly that infrastructure construction investment constitutes a major part (61%).[12]

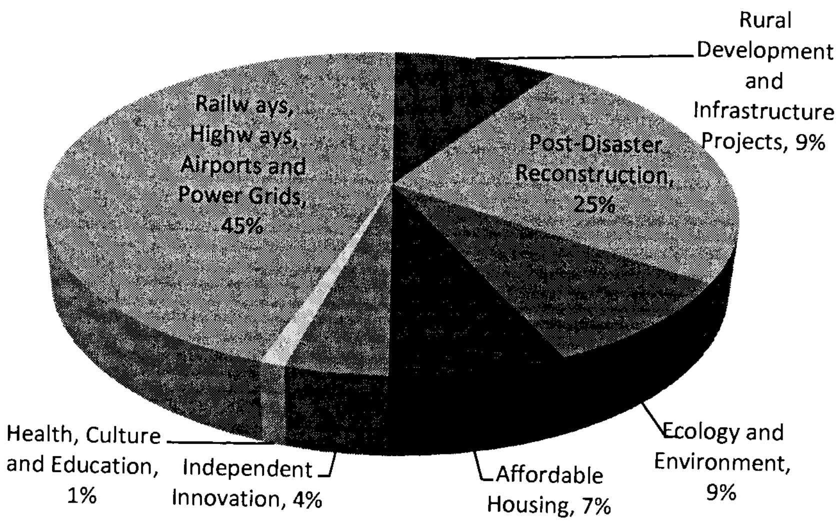

Chart 1: The composition of 4 trillion Yuan investment package in 2008

Source: *2009 China infrastructure construction industry report.* GlobalWin Consulting Co.Ltd

Overall, China has been successful in developing its infrastructure during the last half of 20th century and consistently improving its general economic competitiveness. It is interesting to note this success should be attributed to the coordination system of the Chinese infrastructure investment that consists of both central planning and sectoral planning at all levels of government. The National Development and Reform Commission (NDRC), power center of this system, is obliged to enact and enforce nationwide economic development strategies.[13] Since infrastructure investment had played such a significant role in China's economy, it is important to study its contribution to China's stupendous economic growth in recent decades.

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11 Sahoo, Dash and Nataraj (2010). "Infrastructure Development and Economic Growth in China."

12 "Railw…"+"Rural Development and…"+"Affordable Housing".

13 "Development and Reform Commission's main responsibilities". National Development and Innovation Committee.

3. Literature overview

Various theories stressed infrastructure investment's substantial role in promoting economic growth, compared with other forms of investment. Even though it may not be the locomotive of economic activities, infrastructure investment is still considered a wheel of the economy.[14] However, variations in the results of empirical studies of the effect of infrastructure investment on economic growth exist, reflected in the following three representative standpoints, according to Shi (2009) [15]

3.1 Studies on other countries

3.1.1 Studies that report positive effect

The first standpoint points out that infrastructure investment has positive effect on economic growth. The representative scholar is Aschauer, who was the first to empirically examine the relationship between government spending and economic growth. Aschauer (1989) uses the general Hicks Neutral production function and argues that: (1) nonmilitary public capital stock is dramatically more important in determining economic growth than is either the flow of nonmilitary or military spending; (2) military capital bears little relation to economic growth; and (3) a 'core' infrastructure (streets, highways, airports, mass transit, sewers, water systems, etc.) has most explanatory power for economic growth. His paper also suggests an important role of the net public capital stock in the 'productivity slowdown' of the last fifteen years in the US. He suggests that the decline of growth rate of public capital stock in the US, from 4.1% in 1971 to 1.6% in 1985, is the most important reason for the recession.

The series of articles Aschauer published (1989a, 1989b, 1989c) have started a

[14] World Bank Report (1994).

[15] Shi (2009). "The Relevancy between Infrastructure Input and Economic Growth in the Perspective of Positive Fiscal Policy".

serious focus on infrastructure investment and formed a new hotspot. Subsequent studies such as Munnell (1990), Sanchez-Robles (1998), Lynde and Richmon (1992), Duggala, Saltzmana and Kleinb (1999) report positive and relatively high output elasticity of public infrastructure investment in their own studies, though the elasticity they find is relatively lower than that in Aschauer (1989). Munnell (1990) uses the mixed data of investment, labor force and output in public sectors and private sectors across 48 US states in the period 1970-1986 and shows positive output elasticity of public capital.

Sanchez-Robles (1998) explores empirically the relationship between infrastructure and economic growth by including the data of infrastructure expenditure as a share of GDP in traditional cross-country regression growth model, elaborates some new indicators of infrastructure investment and finds that they are positively and significantly correlated with growth in two different samples of countries. Lynde and Richmon (1992) study the impact of public capital on production cost in the private sector using annual data over the period 1958-1989 in a translog cost function and find public capital to be a significant input. Their results indicate that the marginal productivity of public capital is positive and that private and public capital are complements in production, rather than substitutes. Vijaya (1999) incorporates infrastructure into the production function as part of the technological constraint rather than as a discretionary factor input.

The theoretical model specifies a technical progress rate as a nonlinear function of infrastructure and a time trend, the latter capturing the effect of all other variables on the growth rate in technology. The functional form estimated allows for an S-shaped production function which embodies not only the properties of a long-run production function but also those exhibited in the short run. The evaluation of the growth accounting equation implies that information technology was the largest contributing component to growth during the expansion in the 1990s.

3.1.2 Studies that report negative or unobvious effects

The second type of standpoint shows that the impact of infrastructure investment on economic growth is not obvious or even negative. For instance, Tatom (1993) argues that the causality direction between infrastructure investment and economic growth is not unique, and indicates that public capital is a normal good; economic growth would boost the demand for the quantity of public capital. Instead of using an aggregate production function, his paper employs a traditional cost-benefit framework.

Grihfield (1994) shows that public infrastructure investment has an unclear contribution to the economic growth. Garcia-Mila, McGuire, and Porter (1996) analyze this question using different econometrical methods based on the infrastructure data used in Munnel (1992) and conclude that the output elasticity of public infrastructure is not significant. Evans and Karras (1994) use the data of 48 US states during the year 1970-1986, and test the influence of US public investment in the private sector of economic growth. Their result shows that public investment in education has significant positive effect on the economic growth, while other public investment projects have no obvious effect on growth, and some public investment such as roads and water supply and sewage treatment system, etc. even play a negative role in dragging economic growth. Devarajan, Swaroop and Zou (1996) also point out that public infrastructure investment may have a negative contribution to economic growth. Using data of 43 developing countries over 20 years, they show that an increase in the share of current expenditure has positive and statistically significant growth effects. By contrast, the relationship between the capital component of public expenditure and per-capita growth is negative. Thus, seemingly productive expenditures, when used in excess, could become unproductive. These results imply that developing countries' governments have been misallocating public expenditures in favor of capital expenditures at the expense of current expenditures.

3.1.3 Studies that report ambiguous effects

The third type of standpoint is that the impact of public infrastructure investment in economic growth is very complex and dependent on many other concrete situations. For instance, Bougheas, Demetriades and Mamuneas (2000) incorporate infrastructure as a cost-reducing technology in Romer's (1987) model of endogenous growth and indicate that infrastructure can promote specialization and long-run growth, even though its effect on the latter is non-monotonic, subject to its resource costs. They also provide evidence from cross-country regression by using physical measures of infrastructure provision, showing a robust non-monotonic but inverted-U relationship between infrastructure and growth.

Morrison & Schwartz (1996) point out that public infrastructure investment, except for those in research and development sectors, only have a short-run positive effect on economic growth. Using a cost-based methodology, they find that in the short run, public capital expenditures provide cost-saving benefits that exceed the associated investment costs due to substitutability between public capital and private inputs. Over time, however, stimulated investment in private capital increases economic performance more effectively than public capital investment alone and in fact reduces the cost incentive for such expenditures. Therefore, public capital investment only has a short-run significant benefit. In the long-run, it is no longer effective.

Barro (1990) posits that the productive public infrastructure expenditure has a lasting and significant effect on economic growth, depending on its size. If public spending has not yet achieved the optimal scale, it would generate positive effects on growth. When it is more than the optimal size, it will have negative impacts

3.2 Studies on China

Some studies have focused on the relationship between public infrastructure investment and China's economic growth. D´emurger (2000) provides empirical evidence on the links between infrastructure investment and China's economic growth using the now-standard Barro-type framework, which allows for testing for conditional convergence by adding to a Solow-type equation a set of variables to reflect the differences in the steady-state equilibrium. Using panel data from a sample of 24 Chinese provinces (excluding municipalities) throughout 1985 to 1998, he shows that, besides differences in terms of reforms, openness, and geographical location, infrastructure endowment also accounts significantly for observed differences in growth performance across provinces. The results indicate that transportation facilities are a key differentiating factor in explaining the growth gap and telecommunication has an important role in reducing isolation.[16]

Liu (2002) estimates the output elasticity of total public investment and its subdivision items in 29 provinces using the production function approach with mixed data of 29 provinces (excluding Taiwan, Tibet, and Chongqing) during 1996-2000. He shows that, on the whole, the output elasticity of public investment is larger than that of private investment, and public infrastructure investment in scientific research and technology contributes most to the economic growth, and investment in social service project does not have obvious effect, while investment in government agencies and community projects has some negative effects on economic growth. Thus in the situation of insufficient demand (compared to overly supply), to it is reasonable to sustain economic growth target by public investment expansion.[17]

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16 D´emurger, S. (2000) "Infrastructure development and economic growth: an explanation for regional disparities in China?" Journal of Comparative Economics 29, 95–117.

17 Liu (2002). "The public investment and economic growth". Reform. 2002(4).

Liu (2003) takes advantage of co-integration theory and establishes error correction model that reflects short-term volatility of variables and long-term equilibrium by analyzing the data of national infrastructure investment and respective three regional parts infrastructure investment during 1985-2000. He points out that China's infrastructure investment, though a great impetus to economic development, is still less than the world average level. Moreover, infrastructure investment in eastern China regions has the largest positive effect on the nation's economy. Middle China regions take second place, and western China regions contribute the least. So the effect of infrastructure investment on economic growth also differs temporally and geographically.[18]

Zhu (2004) employs a Cobb-Douglas production function and estimates the output elasticity from the data of the national infrastructure stock from 1985 to 2002. This paper indicates that infrastructure capital stock has positive impact on economic growth. Moreover, it shows that the nation-financed infrastructure investment also has a positive effect on economic growth in the same period.

Zhang (2004) uses endogenous growth model to carry out co-integration test and Granger causality test on the correlations between public physical capital investment, public labor investment, R&D investment and economic growth with statistical data from 1980 to 2002. This paper shows that these three public investments exhibit positive effect on economic growth through different channels. Public physical capital investment promotes economic growth mainly through capital accumulation effect, and public labor investment and R&D investment through total factor productivity increase and external effect.[19]

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[18] Liu (2003). "Studies on Promoting effect of Infrastructure Investment in Economic Growth". Doctoral Dissertation, Jiangxi university of finance and economics, China.

[19] Zhang (2004) "the correlative analysis of Public investment and economic growth-- Empirical test with China's data" Financial &Trade Economics. NO .11.

Gao and Li (2006) employs a Computable General Equilibrium model framework to estimate the impact of infrastructure investment in poverty reduction in rural China. He concludes that, in the short-run, the increase of infrastructure investment can promote macroeconomic growth; in the long-run, the most direct beneficial effect of the infrastructure improvement for the poor was improved productivity.

Liu (2009) analyzes the output elasticity of public investment (education investment, infrastructure investment, science and research investment) in the model which integrates a modified Cobb-Douglas production function with endogenous economic growth theory and co-integration theory using public investment statistical data during 1981-2007. This paper points out that from both theoretical and empirical perspectives on China's long-term economic growth, the growth-promoting effect of public investment is obviously positive. Empirical analysis results indicating such impact to be unclear may have been due to data processing, or the fact that the economic environment and system is unable to absorb and utilize all public investment to boost economic growth.

Liu and Teng (2010) adopt co-integration test, Granger causality test and impulse response analysis to construct a VEC model and a dummy variable model, and estimate the effect of public investment (based on government physical capital investment and human capital investment) on economic growth with monthly statistical data of 1993-2008. The paper finds that public investment has positive and significant long-run effect on economic growth, though short-run effect is unclear. The promoting effect of government-funded public investment in economic growth differs in different periods of time, and is also susceptible to fiscal policy change.

Tang (2010) establishes a production function model with three elements to estimate output elasticity of infrastructure investments with statistical data from 1994 to 2008 in the central region of China. The paper finds that the output elasticity of public infrastructure investment is 0.3710%. Moreover, taking advantage of Johansen co-integration test and VAR model, this paper indicates that the impact of public infrastructure construction on economic growth is positive. Using the vector error correction model and Granger causality test, it also indicates that public infrastructure investment is a reason of long-run economic growth, while its short-run effect is not clear.

Guo, Guo and Xia (2010) apply Chinese data of GDP, railway mileage, and highway mileage from 1964 to 2004 in a general VAR framework. A non-stationary test shows that the selected macroeconomic variables are all non-stationary with integration order 1. In addition, co-integration and error-correction analyses show that the selected variables can be co-integrated and indicates a positive promotion of railway investment to GDP and negative promotion of highway investment to GDP in the long run. Social and economic situations related to the analysis are discussed, based on which future research is recommended on handling the data generating mechanism change and the social and economic diversity across different regions in China.

Sahoo, Dash and Nataraj (2010) investigate the role of infrastructure in promoting economic growth in China through the production function approach with vector error correction version of Auto-regression-distributed lag model (ADRL) and Generalized Methods of Moments model (GMM) with statistical data from 1975 to 2007. This research points out that, overall, the results reveal that the infrastructure stock, labor force, and investment have played an important role in economic growth in China. Further, there is unidirectional causality from infrastructure stock to economic growth and bi-directional causality between investment and economic growth. Justifying China's high spending on infrastructure development since the early nineties, the experience of China suggests that it is necessary to design an economic policy that improves the physical infrastructure as well as human capital formation for sustainable economic growth in developing countries.[20]

Wang and Yan (2011) estimate the effect of public investment on economic growth in the Ramsey-Cass-Koopmans model with statistical data during 2004-2009. From the regression results, they find that the government's public investment not only played a direct role in economic growth, but also indirectly promoted China's long-term economic sustainable growth through the impetus of private investment. The spillover effect of public investment was significant. At the same time, they find that public investment did not crowd out private investment, which implicates that government investment in China is appropriate.

In sum, though the role of infrastructure investment in economic growth is under debate, most studies investigating this relationship in China reveal that infrastructure investment indeed contributed positively to economic growth. There still remains an unanswered question: is the large-scale infrastructure investment led by Chinese government enough to boost economic growth. This question is the purpose of this paper.

4. Methodology

4.1 Background

In the literature, especially from the standpoint of Baird (2005), Guo, Guo, Xia (2010) and Zhang (2004), there exist three mainstream empirical test methods:

4.1.1 Production Function Approach

The aggregated production function model, first used in Aschauer (1989a), is the most common instrument to investigate the impact of infrastructure investment on economic growth. An aggregated production function can be defined as:

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[20] Sahoo, Dash and Nataraj (2010). "Infrastructure Development and Economic Growth in China." IDE Discussion Paper, NO.261.

$$Y_t = A_t \cdot f(N_t, K_t, G_t) \tag{1}$$

where Y_t represents the aggregate output (i.e., GDP), A_t total factor productivity, N_t labor force, K_t aggregated capital stock and G_t public infrastructure capital stock, at time *t*. $f(\cdot)$ is usually a Cobb-Douglas production function:

$$Y_t = A_t \cdot N_t^{\alpha} \cdot K_t^{\beta} \cdot G_t^{1-\alpha-\beta} \tag{2}$$

By taking natural log of (2) and adding the error term ε_t, we get:

$$\ln(Y_t) = \ln(A_t) + \alpha\ln(N_t) + \beta\ln(K_t) + (1-\alpha-\beta)\ln(G_t) + \varepsilon_t \tag{3}$$

where $1-\alpha-\beta$ is output elasticity of public infrastructure. However, though widely employed in many studies, this approach is mostly criticized for its inability in revealing the possibly reverse causality between growth and infrastructure investment (Gramlich,1994) and in showing the channel in which infrastructure investment stimulates the economy (Baird, 2005).

4.1.2 Cost Function or Profit Function Approach

The cost function approach shows whether infrastructure investment contributes to economic development and how its contribution is realized (Baird, 2005). Assuming implicitly that the cost function represents the behavior of private firms about their demand and use of inputs, a common cost function in this approach can be described as (Banister and Berechman, 2000):

$$C = f(w, K_p, K_g, t, Y) \tag{4}$$

where C is the cost function of private sector, w the input price vectors, K_p private capital, K_g public capital, t the time index, Y output. The cost elasticity of infrastructure investment or the cost saving from the infrastructure investment can be defined as:

$$\partial lnC / \partial lnK_g \tag{5}$$

Compared with the production function approach, the cost function approach describes the firm's optimization behavior by treating both inputs and outputs as endogenous variables while leaving only prices as exogenous variables. This approach, however, is limited sometimes by the unavailability of the public infrastructure price data and the difficulty in calculating the cost reduction. (Baird, 2005).

4.1.3 Vector Auto-regression Approach (VAR)

Compared with the production function and cost function approaches, the VAR approach offers a more flexible framework in which the variables are treated symmetrically as endogenous and the relationship between variables in question can be inferred without assumption of a prior restriction (Sims et al., 1990). Each variable has an equation explaining its evolution based on its own lags and the lags of all the other variables in the model. So it is in accordance with the inherent characteristics of data in the long-term equilibrium.

A VAR model describes the evolution of a set of k endogenous variables over the same sample period ($t = 1, \ldots, T$) as a linear function of their past evolution only. A pth order VAR process can be defined as:

$$Y_t = c + \sum_{i=1}^{p} \varphi_i Y_{t-i} + \varepsilon_t \tag{6}$$

where c is a $k \times 1$ vector of constants, φ_i a $k \times k$ coefficient matrix (for every $i = 1, \ldots, p$) and ε_t a $k \times 1$ vector of white-noise process, thus $E(\varepsilon_t) = 0$, $E(\varepsilon_t \varepsilon_t^T) = \Sigma$, $E(\varepsilon_t \varepsilon_s^T) = 0$ for $t \neq s$.

From the comparison above, we can see that VAR model befitting best our need, thus we use a VAR framework for our study.

As we know, a VAR model can be unrestricted or restricted. In an unrestricted VAR model, the series data can be used directly and consistently. The coefficient estimates can be obtained through ordinary least square approach (OLS) irrespective of the stationary property (Sims et al, 1990). However, the estimated coefficients in the unrestricted VAR model are usually less useful for making inference. Commonly, in economic analysis, unrestricted VAR should be necessarily restricted by certain conditions, which is the restricted VAR.

Thus, in this paper, the generalized unrestricted VAR model would be first introduced; then the restricted VAR model would be put forward with the restrictions of stationary test (ADF test), co-integration test (Johansen), the vector error correction mode and Granger causality test.

4.2 Model specification and estimation procedure

4.2.1 Unrestricted VAR model

In (6), if all the variables in this VAR model do not have a unit root, then they can be regarded as stationary, and can be estimated through OLS or maximum likelihood estimation (MLE) methods. In case of non-stationarity VAR model, the OLS method can also be used to generate consistent VAR model parameter estimates, or achieve stationary before further analysis using differencing operator (Sims et al., 1990).

4.2.2 Restricted VAR model

Unrestricted VAR model is seldom applied, however, since economic data are usually too complicated to be naturally stationary. Thus the restricted VAR model should be employed by adding two common restrictions: stationary test and the co-integration test.[21]

The first restriction is related to the stationary test. Many economic and financial time series data exhibit trend behavior or non-stationarity in the mean. Therefore, it is important to determine whether the data used is stationary or not. Commonly, the Dickey–Fuller test (DF) is a test for a unit root to decide whether the variables are

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[21] Guo, Guo and Xia (2010). "Econometrical Investigation on Infrastructure Investment and Economic Development in China: A Case Study Using Vector Auto-regression Approach" KSCE Journal of Civil Engineering 15(3),561-567.

stationary in time series (Dickey and Fuller, 1979, 1981). There is an augmented version of the Dickey–Fuller test (ADF) for a larger and more complicated set of time series models. Thus, ADF test will be applied in this paper. In general, there are three types of ADF test (Sargan and Bhargava, 1983):

1. When the time series is flat (i.e. doesn't have a trend) and potentially slow-turning around zero, the following test equation without a constant and trend should be used:

$$Y_t = p \cdot Y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta Y_{t-i} + \varepsilon_t \quad (7)$$

2. When the time series is flat and potentially slow-turning around a non-zero value, the following test equation only with a constant should be used:

$$Y_t = C_t + p \cdot Y_t + \sum_{i=1}^{p} \varphi_i \Delta Y_{t-i} + \varepsilon_t \quad (8)$$

3. When the time series has a trend in it and is potentially slow-turning around a trend line you would draw through the data, the following test equation with a constant and a trend should be used:

$$Y_t = C_t + \beta_t + p \cdot Y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta Y_{t-i} + \varepsilon_t \quad (9)$$

In general, null hypothesis of the test is that there is a unit root in the series. If no unit root is found in the test, the unrestricted VAR model could be applied; if a unit root can be found in a time series variable, and the 1st order differenced time series variable do not have a unit root, then the series is said to be integrated at order 1, denoted by *I(1)*.

The second restriction is the co-integration and vector error correction method. As pointed out by Engle, Robert, Granger and Clive (1987), if two or more series are individually integrated (in the time series sense) but some linear combination of them has a lower order of integration, then the series are said to be co-integrated. A common example is where the individual series are all integrated at first-order (*I(1)*) but some (co-integrating) vector of coefficients exists to form a stationary linear combination of them. Thus, from the ADF test, if the variables are non-stationary, the co-integration method should be applied to decide whether these variables can be co-integrated. Several co-integration test methods have been presented: Engle-Granger Two-Step test (Engle, Robert, Granger and Clive, 1987), Johansen's co-integration rank test (Johansen, 1988), Phillips-Ouliaris co-integration Test (Phillips-Ouliaris, 1990). In this paper, Johnson's co-integration rank test will be employed, considering the multivariate nature of VAR model, and the convenience of the Johansen approach by treating all variable as jointly endogenous (Dickey et al., 1991 and Tang, 2010).

As to the vector error correction model, in reality, it is a restricted VAR model. We can get it from the famous Granger Representation Theorem put forward by Engle and Granger (1987), which indicates that the vector error correction model (VECM) is a dynamical system with the characteristics that the deviation of the current state from its long-run relationship will be fed into its short-run dynamics and can also improve longer term forecasting over an unconstrained model.[22] Any VECM with co-integrated VAR model can be described as:

$$\Delta Y_t = \Pi \cdot Y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta Y_{t-i} + \varepsilon_t \tag{10}$$

where Δ is the differencing operator, $\Pi = \alpha\beta^T$, α is the adjustment parameter, β is the long-term parameter. Moreover, the VECM model is used to investigate whether there is a reverse revise function when the short-term diverges from the long-term equilibrium between economic development and infrastructure investment.

The third part of the empirical test comes to a causality correlation test. Though the co-integration test can determine whether there is a long-term relationship between variables in the model, these co-integration equations do not show the

[22] Engle and Granger (1987). "Co-Integration and error correction: Representation, estimation, and testing." Econometrica 55, No.2, 251-276.

direction of these relationships. Therefore, infrastructure improvements may promote the economic growth, or economic growth may drive up infrastructure investment. In general, Granger causality test is a statistical hypothesis test for determining whether one time series is useful in forecasting another. Granger (1969) pointed out that according to Granger causality, if a signal X_1 "Granger-causes" (or "G-causes") a signal X_2, then past values of X_1 should contain information that helps predict X_2 beyond the information contained in past values of X_2 alone. Thus this paper employs a Granger causality test to determine the causality directions among variables.

In sum, this paper will employ restricted VAR by incorporating the ADF stationary test, Johansen co-integration test, and VECM to estimate the relationship between infrastructure investment and the economic growth.

5. Data Resource and Empirical Estimation Results Analysis

5.1 Variable selection and data resource

This paper considers the concept of generalized infrastructure, which includes not only core infrastructure, such as the transportation, post and communication, but also social infrastructure, such as education, health care and research in technology. The reason for this is that the social infrastructure is correlated with the construction of human capital, and the development of which is important to economic growth. As mentioned in the introduction, this paper also takes advantage of aggregated annual time series macroeconomic data. The detailed descriptions of data are as follows: (1) the change in GDP is chosen as a proxy measure of economic growth, which is internationally recognized as an effective index to reflect economic growth. (2) In addition, except infrastructure investment, many other economic variables also have impact on economic growth. Thus, we should consider the influence of other variables on the economic growth, which will help reflect the true relationship between infrastructure investment and economic growth. Of course, the principle in the selection of other variables is to choose variables that both are correlated with output and infrastructure development. Under comprehensive consideration, this paper added two economic variables: the employed population (denoted as PP) and the total import and export volume (denoted as TX). (3) Then we consider the industrial sector GDP: Primary industry GDP (denoted as GDPP); Secondary industry GDP (denoted as GDPS); Tertiary industry GDP (denoted as GDPT). They represent the economic growth in these industries respectively.

According to Liu (2002), there are two basic characteristics of public infrastructure investment: first, it consists of investment by central and local governments; second, it is the investment of central and local government in the field of infrastructure and public service. In China, within the data of fixed assets investment published by the National Bureau of Statistics, there is a category that can be used to distinguish between public investment and the non-public investment. The category of sources of funds for investment and structure of investment in fixed assets can be divided into state budget investment, domestic loans, foreign investment, and self-raising funds.

The state budget investment in fixed assets can then be seen as public investment. (4) Total infrastructure investment financed by state budget (denoted as TSBI), which is represented by the total fixed asset investment financed by the state budget. (5) Infrastructure investment in agriculture (denoted as TIA), which is represented by the total fixed asset investment in agriculture. (6) Infrastructure investment in mining (denoted as TIM), which is represented by the total fixed assets investment in mining. (7) Infrastructure investment in transportation, postal telecommunication, education, health care, scientific research, culture and sports (denoted as TITPEH), which is also represented by the fixed assets investment in these industries. Although not all investment in (5)(6)(7) comes from state budget, in these industries, most of the investment are financed by the state or the state-owned corporations; for instance, almost all the water conservation facilities, transportation, education, scientific research establishments are invested by the government, and almost all mining facilities, telecommunication and postal facilities are owned by the state-run corporations. Of course, the data used in this paper is biased towards the real public infrastructure investment. Even in the presence of private investment in these industries, the share of private investment is fairly small, thus data of public investment can approximately represent these industries.

The sample period of the data is from 1978 to 2009. Also note that data used in this paper is recalculated from the *China Statistical Yearbook 1985-2010*. Moreover, all the variables have been modified to real number through the consumer price index (CPI) (1978=100).[23] In addition, to reduce any potential hetero-scedasticity and normalize the ranges of these series, we use a natural log transformation of these variables. The natural log transformation of the GDP can be denoted as LGDP; the natural log transformation of employed population as LPP; the natural log transformation of employed population as LTX; the natural log transformation of the GDP in primary industry as LGDPP; the natural log transformation of the GDP in secondary industry as LGDPS; the natural log transformation of the GDP in the tertiary industry as LGDPT; the natural log transformation of the total infrastructure investment as LTSBI; the natural log transformation of the infrastructure investment in agriculture as LTIA; the natural log transformation of infrastructure investment in mining as LTIM; and the natural log transformation of infrastructure investment in transportation, post, education and health care as LTITPEH.

[23] The adjustment should have been through GDP deflator or Fixed Asset Investment Price Index. These indices, however, are incomplete in China during our sample period.

5.2 Empirical Estimation Results Analysis

5.2.1 Stationary test

Generally speaking, most of the economic time series are not stationary, thus stationary test must be taken before the co-integration test, otherwise using non-stationary data will easily lead to spurious regression. As mentioned before, this paper will employ ADF test to inspect whether there is unit root in the time series. Using Eviews7® software, this paper take ADF test on LGDP, LPP, LTX, LGDPP, LGDPS, LGDPT, LTSBI, LTIA, LTIM, LTITPEH, respectively.

Table 1: ADF unit root test results

Sample period: 1978-2009

Variables	Test form	ADF statistics	Critical Value (5%)	Critical Value (1%)	Conclusion
LGDP	(c, 0)	1.743024	-2.976263	-3.699871	non
LGDPP	(c, 0)	-0.809415	-2.960411	-3.661661	non
LGDPS	(c, 0)	1.168263	-2.967767	-3.679322	non
LGDPT	(c, 0)	0.973115	-2.96041	-3.661661	non
LTSBI	(c, 0)	0.409112	-2.960411	-3.661661	non
LTIA	(c, 0)	0.758448	-2.960411	-3.661661	non
LTIM	(c, 0)	1.772524	-2.960411	-3.661661	non
LTITPEH	(c, 0)	1.691594	-2.960411	-3.661661	non
LPP	(c, 0)	-2.417161	-2.960411	-3.661661	non
LTX	(c, 0)	-1.421434	-2.960411	-3.661661	non
D(LGDP)	(c, 0)	-4.087765	-2.967767	-3.679322	stationary
D(LGDPP)	(c, 0)	-6.224085	-2.963972	-3.670170	stationary
D(LGDPS)	(c, 0)	-4.057726	-2.967767	-3.679322	stationary
D(LGDPT)	(c, 0)	-3.538107	-2.963962	-3.670170	stationary
D(LTSBI)	(0, 0)	-2.702794	-1.952473	-2.644302	stationary
D(TIA)	(c, 0)	-4.579019	-2.963922	-3.670170	stationary
D(TIM)	(c, 0)	-4.860447	-2.963972	-3.670170	stationary
D(TITPEH)	(c, 0)	-3.409818	-2.963972	-3.670170	stationary
D(LPP)	(c, 0)	-5.040379	-2.963922	-3.670170	stationary
D(LTX)	(c, 0)	-3.536935	-2.963972	-3.670170	stationary

Note: The sample period of variables tested in table1 are all from the year 1978 to 2009. And D means the first-order difference operator. In the test forms, c and t, respectively, represent the unit root test equation with time constant or a trend. And non in the conclusion means non-stationary.

The results reveal that all series are non-stationary, and after taking first order difference, all the series become stationary, indicating that all the series used in this paper are integrated at order 1 at 5% confidence level, denoted by ***I(1)***. Table 1 above shows detailed results. Thus, because all the time series satisfy ***I(1)***, there is a possibility that they can be co-integrated.

5.2.2 Co-integration and VAR

According to Wang and Wang (2007), though stationary test results warrant the test of co-integration, determining the structure of the VAR model is crucial before taking co-integration test. Two questions must be clear in the process of constructing VAR model: (1) how are the variables related to each other; and (2) how to determine the order of VAR model to make the model reflect most of the relationships among variables. This paper mainly inspects the relationship between infrastructure investment and economic growth. Population and total import and export volume are added to these models for their correlation with both infrastructure investment and economic growth. Therefore, in this paper the VAR models mainly include the infrastructure variable (LTSBI, LTIA, LTIM, LTITPEH) and aggregate output (LGDP), output in primary industry (LGDPP), output in secondary industry (GDPS), output in tertiary industry (LGDPT), employed population (LPP) and total import and export volume (LTX). Thus five VAR models will be established, respectively: Y_1=(LGDP, LTSBI, LPP, LTX), which describes the impact of total infrastructure investment in economic growth; Y_2=(LGDP, LTIA, LTIM, LTITPEH, LPP, LTX), which represents the impact of infrastructure investment in agriculture, mining, transportation, post, education and health care on economic growth; Y_3=(LGDPP, LTIA, LPP, LTX), which describes the impact of infrastructure investment in agriculture on the GDP in the primary industry; Y_4=(LGDPS, LTIM, LPP, LTX), which describes the impact of infrastructure investment in mining on the GDP in the secondary industry; Y_5=(LGDPT, LTITPEH,LPP, LTX), which represents the impact of infrastructure investment in transportation, post, education and health care.

Besides the determination of the variables contained in these VAR models, the selection of order of lags k in VAR models is also crucial. If k is too small, the possibility of autocorrelation of the error terms would be very serious. Of course, appropriately increasing the order of lags k, to some extent, can eliminate the existence of autocorrelation of the error terms, while if k is too large, it will reduce the efficiency of the estimators of model parameter for the loss of degrees of freedom (Yang and Xiong, 2010).

In order to eliminate autocorrelation of the error terms while keeping reasonable degrees of freedom, this paper would select the maximum lag order number based on many VAR lag order selection criteria, such as LR, FPE, AIC, SC and HQ information minimum criteria.

As to the co-integration test, in this paper, Johansen's co-integration rank test is performed within unrestricted VAR models. And the lag orders of the co-integration test is that of the unrestricted models after first order difference, thus when the lag order of unrestricted VAR model is VAR(k), the lag order of the co-integration test is $k-1$ (Wang and Wang, 2007).

By VAR lag order selection criteria, the maximum lag order of the first VAR model Y_1=(LGDP, LTSBI, LPP, LTX) is 4, thus the lag order of the co-integration test is 3 and the result of Johansen's co-integration rank test is shown in Table 2.

Table 2: Co-integration rank test results of the VAR model

Y_1= (LGDP, LTSBI, LPP, LTX)

Sample period: 1978-2009

Null hypothesis H_0	Eigenvalue	Trace Statistic	Critical Value (5%)	Max-Eigen Statistic	Critical Value (5%)
None *	0.775101	78.68174	47.85613	41.77885	27.58434
At most 1 *	0.573445	36.90288	29.79707	23.85637	21.13162
At most 2	0.297067	13.04652	15.49471	9.869807	14.26460
At most 3	0.107255	3.176711	3.841466	3.176711	3.841466

In Table 2, both trace statistic and the max-eigen statistic show that there are two co-integration equations at 5% confidence level, which indicates the existence of the long-run equilibrium correlations among aggregated output (LGDP), the total infrastructure investment (LTSBI), employed population (LPP), and total import and export volume (LTX).

By the VAR lag order selection criteria, the maximum lag order of the second VAR model Y_2=(LGDP, LTIA, LTIM,LTITPEH, LPP, LTX) is 3, thus the lag order of the co-integration test is 2 and the result of Johansen's co-integration rank test is shown in Table 3 below:

Table 3: Co-integration rank test results of the VAR model

Y_2=(LGDP, LTIA, LTIM,LTITPEH, LPP, LTX)

Sample period: 1978-2009

Null hypothesis H_0	Eigenvalue	Trace Statistic	Critical (5%)	Max-Eigen Statistic	Critical Value (5%)
None *	0.955535	232.2775	95.75366	90.27874	40.07757
At most 1 *	0.887243	141.9988	69.81889	63.29316	33.87687
At most 2 *	0.756128	78.70564	47.85613	40.92226	27.58434
At most 3 *	0.566265	37.78338	29.79707	24.22433	21.13162
At most 4	0.317103	13.55905	15.49471	11.06092	14.26460
At most 5	0.082537	2.498137	3.841466	2.498137	3.841466
None *	0.955535	232.2775	95.75366	90.27874	40.07757

In Table 3, both trace statistic and the max-eigen statistic show that there are four co-integration equations at 5% confidence level, which indicates the existence of the long-run equilibrium correlations among aggregated output (LGDP), infrastructure investment in agriculture (LTIA), mining (LTIM), transportation, post education and health care (LTITPEH), employed population (LPP), and total import and export volume (LTX).

By the VAR lag order selection criteria, the maximum lag order of the third VAR model Y_3=(LGDPP, LTIA, LPP, LTX) is one, thus the lag order of the co-integration test is 0 and the result of Johansen's co-integration rank test is shown in Table 4 below:

Table 4: Co-integration rank test results of the VAR model Y_3=(LGDPP, LTIA,LPP,LTX)

Sample period: 1978-2009

Null hypothesis H_0	Eigenvalue	Trace Statistic	Critical Value (5%)	Max-Eigen Statistic	Critical Value (5%)
None *	0.573274	41.64838	40.17493	25.54843	24.15921
At most 1 *	0.284969	16.09995	24.27596	10.06289	17.79730
At most 2	0.181569	6.037066	12.32090	6.010980	11.22480
At most 3	0.000869	0.026086	4.129906	0.026086	4.129906

In Table 4, both trace statistic and the max-eigen statistic show that there is one co-integration equation at 5% confidence level, which indicates the existence of the long-run equilibrium correlations among GDP in the primary industry (LGDPP), infrastructure investment in agriculture (LTIA), employed population (LPP), total import and export volume (LTX).

By the VAR lag order selection criteria, the maximum lag order of the fourth VAR model Y_4=(LGDPS, LTIM, LPP, LTX) is three, thus the lag order of the co-integration test is two and the result of Johansen's co-integration rank test is shown in Table 5.

And in Table 5, the trace statistic shows that there are 2 co-integration equations at 5% confidence level, while the max-eigen statistic shows that threre are 3 co-integration equations at 5% confidence level, which indicates the existence of the long-run equilibrium correlations among GDP in the secondary industry (LGDPS), infrastructure investment in mining (LTIM), employed population (LPP), and total import and export volume (LTX).

Table 5: Co-integration rank test results of the VAR model

Y_4=(LGDPS, LTIM, LPP, LTX)

Sample period: 1978-2009

Null hypothesis H_0	Eigenvalue	Trace Statistic	Critical Value(5%)	Max-Eigen Statistic	Critical Value(5%)
None *	0.701240	73.07438	47.85613	35.03528	27.58434
At most 1 *	0.542346	38.03909	29.79707	22.66763	21.13162
At most 2	0.403379	15.37146	15.49471	14.97774	14.26460
At most 3	0.013485	0.393715	3.841466	0.393715	3.841466

By the VAR lag order selection criteria, the maximum lag order of the fifth VAR model Y_5=(LGDPT, LTITPEH, LPP, LTX) is two, thus the lag order of the co-integration test is one and the result of Johansen's co-integration rank test is shown in Table 6 below:

Table 6: Co-integration rank test results of the VAR model

Y_5=(LGDPT, LTITPEH, LPP, LTX)

Sample period: 1978-2009

Null hypothesis H_0	Eigenvalue	Trace Statistic	Critical Value(5%)	Max-Eigen Statistic	Critical Value(5%)
None *	0.655283	62.92985	54.07904	31.95091	28.58808
At most 1 *	0.417799	30.97894	35.19275	16.22821	22.29962
At most 2	0.298268	14.75073	20.26184	10.62611	15.89210
At most 3	0.128455	4.124620	9.164546	4.124620	9.164546

In Table 6, both the trace statistic and the max-eigen statistic show that there is one co-integration equation at 5% confidence level, which indicates the existence of the long-run equilibrium correlations among GDP in the tertiary industry (LGDPT), infrastructure investment in transportation, post, education and health care (LTITPEH), employed population (LPP), and total import and export volume (LTX).

From these test results, it can be seen that there is at least one co-integration relationship in all the VAR models above, which suggests that there is a long-run relationship among GDP, industrial GDP, infrastructure investment, employed population and total import and export volume. And as pointed out by Zhang (2000), the criteria of the long-term equilibrium are as follows: if there is only one co-integration correlation, then this co-integration correlation is the long-term equilibrium correlation; however, if several co-integration correlations exist in a model, then generally the co-integration correlation with the maximum eigenvalue would be chosen as the long-term equilibrium.

5.2.3 Co-integration Equations (CE) and Vector Error Correction Model (VECM)

According to the co-integration results, it is safe to conclude that the variables in each model can be co-integrated, indicating that there exist long term equilibriums in these VAR models. And the long-term equilibrium can be represented as co-integration equations with normalized co-integrating coefficients. Further, VECM process was then estimated as

$$\Delta Y_t = \Pi \cdot Y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta Y_{t-i} + \varepsilon_t ,$$

where Δ is the differencing operator, $\Pi = \alpha\beta^T$, α is the adjustment parameter, β is the long-term parameter. Then, we can obtain the co-integration equations and VECM estimation equations of all models as below:

(1) The co-integration equation of VAR model, which shows the long-run

correlations between the total infrastructure investment (LTSBI) and the aggregated output (LGDP) and the VECM estimation equation, can be defined as below (the numbers in the square brackets under coefficients are the t-statistics):

Table 7: VECM1 (D(LGDP), D(LTSBI),D(LTX), D(LPP)) estimate results

Error Correction	D(LGDP)	D(LTSBI)	D(LTX)	D(LPP)
CointEq1	-0.107320 [0.64955]	-0.311462 [5.32008]	-1.746221 [-2.75493]	-0.049430 [-0.40274]
D(LGDP(-1))	0.526484 [1.51869]	-3.094425 [-2.51909]	1.114780 [0.83821]	-0.385041 [-1.49517]
D(LGDP(-2))	-0.669168 [-1.72267]	0.390488 [0.28369]	0.820116 [0.55032]	0.073219 [0.25374]
D(LGDP(-3))	0.020313 [0.04856]	-2.402465 [-1.62072]	-1.866756 [-1.16315]	0.225284 [0.72494]
D(LTSBI(-1))	0.078991 [1.56519]	0.650254 [3.63620]	0.060584 [0.31291]	-0.019498 [-0.52010]
D(LTSBI(-2))	-0.030518 [-0.55994]	-0.137241 [-0.71063]	-0.186970 [-0.89419]	-0.029573 [-0.73043]
D(LTSBI(-3))	-0.037322 [-0.70245]	0.000850 [0.00451]	-0.099438 [-0.48785]	0.012237 [0.31005]
D(LTX(-1))	0.138987 [1.45168]	1.117601 [3.29430]	-0.080922 [-0.22031]	-0.000140 [-0.00197]
D(LTX(-2))	0.078405 [0.83814]	0.512146 [1.54506]	-0.311630 [-0.86834]	-0.051116 [-0.73557]
D(LTX(-3))	-0.008459 [-0.10767]	-0.065530 [-0.23539]	-0.147391 [-0.48901]	-0.046623 [-0.79886]
D(LPP(-1))	-0.353056 [-0.72185]	2.663130 [1.53664]	-3.083983 [-1.64358]	-0.299202 [-0.82350]
D(LPP(-2))	0.001033 [0.00194]	1.110605 [0.58727]	-4.328545 [-2.11406]	0.192767 [0.48621]
D(LPP(-3))	0.256879 [0.69535]	3.331373 [2.54494]	-2.685006 [-1.89451]	0.217636 [0.79306]
C	0.075004 [1.69157]	0.132989 [0.84645]	0.437669 [2.57295]	0.044488 [1.35066]
R-squared	0.632371	0.823178	0.559646	0.576314
Log-likelihood	63.73209	28.30957	26.08518	72.05529

Sample period: 1978-2009

The co-integration Equation 1:

$$\text{LGDP} = 0.24\text{LTSBI} + 0.27\text{LTX} + 1.56\text{LPP} - 11.3$$

(11)

[-6.29794] [-4.37664] [-4.86942]

The VECM estimate of equation 1 can be seen from Table 7:

$$\text{D(LGDP)} = -0.11\text{ECM}(-1) + 0.52\text{D}(\text{LGDP}(-1)) - 0.67\text{D}(\text{LGDP}(-2)) +$$

$$0.02D(LGDP(-3)) + 0.08D(LTSBI(-1)) - 0.03D(LTSBI(-2)) - 0.04D(LTSBI(-3)) + 0.14D(LTX(-1)) + 0.09(LTX(-2)) - 0.01D(LTX(-3)) - 0.35D(LPP(-1)) + 0.001D(LPP(-2)) + 0.26D(LPP(-3)) + 0.07 \quad (12)$$

As can be seen from the co-integration Equation 1, the total infrastructure investment financed by the state budget has a positive impact on economic growth. *Ceteris paribus*, one unit change in total infrastructure investment (LTSBI) will contribute positively 0.24 units change in the GDP (LGDP). Moreover, the coefficient of determination R^2 is 0.63, suggesting a good fit of the model to the data. And as can be seen from the VECM estimate Equation 1 and Table 7, that the adjustment parameter is significantly negative (-0.11) ensures the variables make reverse revision when the short-term diverges from the long-term equilibrium (Ba and Wang, 2009).

(2) The co-integration equation of VAR model 2, which shows the long-run correlations between the aggregated output (LGDP) and infrastructure investment in agriculture (LTIA), infrastructure investment in mining (LTIM), infrastructure investment in transportation, post, education and health care (LTITPEH) and the VECM estimation equation, can be defined as below (the numbers in the square brackets under coefficients are the t-statistics):

The co-integration Equation 2:

$$LGDP = -0.12LTIA + 0.12LTIM + 0.79LTITPEH - 0.47LTX + 2.12LPP + 14.87$$

[7.70526] [-5.78461] [-26.1596] [10.2150] [-17.3126] (13)

The VECM estimate of equation 2 is in Table 8:

$$D(LGDP) = -0.008ECM(-1) + 0.819D(LGDP(-1)) - 0.927D(LGDP(-2)) - 0.028D(LTIA(-1)) + 0.0003D(LGDP(-3)) + 0.022D(LTIM(-1)) + 0.066D(LTIM(-2)) + 0.148D(LTITPEH(-1)) - 0.150D(LTITPEH(-2)) - 0.031D(LTX(-1)) + 0.107D(LTX(-2)) -$$

$$0.77D(LPP(-1)) - 0.56D(LPP(-2)) + 0.1 \quad (14)$$

Table 8: VECM2 (D(LGDP), D(LTIA),D(LTIM), D(LTITPEH), D(LTX), D(LPP)) estimate results

Error Correction	D(LGDP)	D(LTIA)	D(LTIM)	D(LTITPEH)	D(LTX)	D(LPP)
CointEq1	0.008754 [-0.08296]	1.677681 [-0.83441]	0.596133 [0.54414]	-0.026086 [-0.03601]	0.074097 [-0.11558]	0.255526 [2.80107]
D(LGDP(-1))	0.819999 [4.03724]	0.265123 [0.06851]	0.026361 [0.01250]	2.353693 [1.68790]	0.875193 [0.70925]	0.795517 [-4.53050]
D(LGDP(-2))	0.927334 [-3.03610]	2.882926 [0.49536]	4.110349 [-1.29617]	1.161265 [0.55378]	1.672117 [-0.90110]	0.403216 [-1.52702]
D(LTIA(-1))	0.028751 [-1.69484]	0.075879 [0.23475]	0.049490 [-0.28100]	0.104634 [0.89842]	0.157840 [-1.53153]	0.022865 [-1.55912]
D(LTIA(-2))	0.000298 [0.01769]	0.373804 [-1.16491]	0.138754 [0.79358]	-0.025631 [-0.22169]	0.097085 [0.94890]	0.012846 [0.88235]
D(LTIM(-1))	0.022636 [0.73970]	0.223271 [0.38291]	0.083240 [0.26199]	-0.114477 [-0.54487]	0.060533 [0.32559]	0.045722 [1.72822]
D(LTIM(-2))	0.066766 [2.31181]	0.342330 [0.62209]	0.258493 [0.86209]	0.017978 [0.09067]	0.077098 [0.43941]	0.024685 [0.98870]
D(LTITPEH(-1))	0.148847 [2.58303]	0.467708 [-0.42596]	0.259745 [0.43415]	0.173575 [0.43874]	0.411354 [1.17499]	0.060038 [1.20516]
D(LTITPEH(-2))	0.150162 [-3.03646]	0.353298 [0.37494]	0.265676 [-0.51744]	-0.224005 [-0.65977]	0.369857 [-1.23103]	0.010077 [0.23571]
D(LTX(-1))	0.031610 [-0.53845]	0.333397 [-0.29805]	0.570690 [0.93632]	-0.080926 [-0.20078]	0.092890 [0.26044]	0.040203 [0.79214]
D(LTX(-2))	0.107224 [1.97883]	1.574577 [-1.52507]	0.185637 [0.32998]	-0.246813 [-0.66345]	0.061902 [0.18804]	0.023892 [0.51003]
D(LPP(-1))	0.077709 [-0.22967]	0.099619 [0.01545]	3.900666 [-1.11040]	1.186619 [0.51083]	0.566887 [0.27578]	0.561728 [-1.92039]
D(LPP(-2))	0.560002 [-1.71394]	5.403216 [0.86789]	3.665881 [-1.08066]	0.409034 [0.18234]	1.225497 [-0.61737]	0.393880 [-1.39443]
C	0.100175 [2.85077]	0.022342 [-0.03337]	0.506094 [1.38720]	-0.155108 [-0.64293]	0.189605 [0.88814]	0.128400 [4.22663]
R-squared	0.802668	0.237165	0.262651	0.476040	0.388563	0.679511
Log-likelihood	74.87268	10.59870	7.009484	19.00381	22.54959	79.09458

Sample period: 1978-2009

As can be seen from the co-integration Equation 2, infrastructure investment in mining and transportation, post, education, and health care all have positive impact on economic growth, while the infrastructure investment in agriculture has negative impact on economic growth. *Ceteris paribus*, one unit change in the infrastructure investment in agriculture (LTIA) will contribute negatively 0.12 units change in the GDP (LGDP). *Ceteris paribus*, one unit change in infrastructure investment in mining (LTIM) will contribute positively 0.12 units change in the GDP (LGDP). *Ceteris paribus*, one unit change in infrastructure investment in transportation, post, education and health care (LTITPEH) will contribute positively 0.79 units change in the GDP (LGDP). Moreover, that the coefficient of determination R^2 is 0.80 suggests a good fit of the model to the data. And as can be seen from the VECM estimate Equation 2 and Table 8, that the adjustment parameter is significantly negative (-0.008) ensures the variables make reverse revision when the short-term diverge from the long-term equilibrium.

(3) The co-integration equation of VAR model 3, which shows the long-run correlations between the GDP in the primary industry (LGDPP) and infrastructure investment in agriculture (LTIA), and the VECM estimation equation, can be defined as below (the numbers in the square brackets under coefficients are the t-statistics):

The co-integration Equation 3:

$$\underset{}{\text{LGDPP}} = \underset{[-2.20521]}{0.32\text{LTIA}} - \underset{[1.70764]}{0.25\text{LTX}} + \underset{[-10.0129]}{0.88\text{LPP}} \tag{15}$$

The VECM estimate of equation 3 is in Table 9:

$$\text{D(GDPP)} = -0.05\text{ECM}(-1) - 0.02\text{D}\big(\text{LGDPP}(-1)\big) - 0.001\text{D}\big(\text{LTIA}(-1)\big) + 0.05\text{D}\big(\text{LTX}(-1)\big) - 0.42\text{D}(\text{LPP}(-1)) \tag{16}$$

Table 9: VECM3 (D(LGDPP), D(LTIA),D(LTX), D(LPP)) estimate results

Error Correction	D(LGDPP)	D(LTIA)	D(LTX)	D(LPP)
CointEq1	-0.051675 [-3.10341]	0.076655 [0.57912]	-0.109918 [-2.57255]	-0.036085 [-4.72532]
D(LGDPP(-1))	-0.020514 [-0.10962]	1.166887 [0.78436]	-0.435158 [-0.90615]	-0.170550 [-1.98707]
D(LTIA(-1))	-0.001841 [-0.07359]	0.169540 [0.85252]	-0.014788 [-0.23036]	-0.011522 [-1.00427]
D(LTX(-1))	0.052125 [0.66171]	0.183248 [0.29264]	0.272685 [1.34901]	-0.048704 [-1.34812]
D(LPP(-1))	-0.423102 [-1.10218]	0.566267 [0.18557]	0.325595 [0.33054]	0.036234 [0.20581]
R-squared	0.754344	0. 699367	0.174115	0.319647
Log-likelihood	47.59025	-14.60242	19.31921	70.97614

Sample period: 1978-2009

As can be seen from the co-integration Equation 3, infrastructure investment in agriculture has a positive impact on primary industry GDP. *Ceteris paribus*, one unit change in the infrastructure investment in agriculture (LTIA) will contribute positively 0.32 units change in the GDP in primary industry (LGDPP). Moreover, that the coefficient of determination R^2 is 0.75 suggests a good fit of the model to the data. And as can be seen from the VECM estimate Equation 3 and Table 9, that the adjustment parameter is significantly negative (-0.05) ensures the variables make reverse revision when the short-term diverge from the long-term equilibrium.

(4) The co-integration equation of VAR model 4, which shows the long-run correlations between the GDP in secondary industry (LGDPS) and infrastructure investment in mining (LTIM), and the VECM estimation equation, can be defined as below (the numbers in the square brackets under coefficients are the t-statistics):

The co-integration Equation 4:

$$LGDPS = 0.31LTIM + 0.33LTX + 0.73LPP - 3.64 \quad (17)$$

[-5.75804] [-3.81025] [-2.02516]

The VECM estimate of equation 4 is in Table 10:

$$D(LGDPS) = -0.25ECM(-1) + 0.78D(LGDPS(-1)) - 1.22D(LGDPS(-2)) - 0.08D(LTIM(-1)) + 0.02D(LTIM(-2)) + 0.16D(LTX(-1)) + 0.04D(LTX(-2)) - 1.30D(LPP(-1) - 1.14D(LPP(-2)) + 0.16 \quad (18)$$

Table 10: VECM4 (D(LGDPS), D(LTIM), D(LTX), D(LPP)) estimate results

Error Correction	D(LGDPP)	D(LTIM)	D(LTX)	D(LPP)
CointEq1	-0.246328 [-2.37320]	-0.352033 [-0.54117]	0.338110 [0.82146]	-0.121651 [-1.96372]
D(LGDPS(-1))	0.779489 [3.90622]	-0.070376 [-0.05627]	1.074835 [1.35830]	-0.484564 [-4.06855]
D(LGDPS(-2))	-1.221534 [-3.58402]	-3.159400 [-1.47909]	-1.070213 [-0.79185]	-0.033153 [-0.16298]
D(LTIM(-1))	-0.078071 [-1.61536]	-0.123736 [-0.40851]	0.014440 [0.07534]	-0.021102 [-0.73154]
D(LTIM(-2))	0.024351 [0.64942]	0.303179 [1.29015]	0.109447 [0.73608]	-0.013169 [-0.58843]
D(LTX(-1))	0.158212 [2.22079]	0.683741 [1.53138]	0.269810 [0.95506]	0.025229 [0.59334]
D(LTX(-2))	0.042568 [0.66420]	-0.112119 [-0.27914]	-0.110084 [-0.43315]	0.004975 [0.13006]
D(LPP(-1))	-1.304898 [-2.11880]	-5.148158 [-1.33380]	0.824998 [0.33781]	-0.640092 [-1.74140]
D(LPP(-2))	-1.136047 [-2.16836]	-3.530648 [-1.07527]	0.102425 [0.04930]	-0.189717 [-0.60671]
C	0.163508 [3.26813]	0.505259 [1.61139]	0.080527 [0.40589]	0.087027 [2.91446]
R-squared	0.694909	0.251375	0.274178	0.574385
Log-likelihood	60.01401	6.789417	20.06294	74.98111

Sample period: 1978-2009

As can be seen from the co-integration Equation 4, infrastructure investment in mining has a positive impact on secondary industry GDP. *If other variables hold constant*, one unit change in infrastructure investment in mining (LTIM) will lead 0.31 units positively change in the GDP in secondary industry (LGDPS). Moreover, that the coefficient of determination R^2 is 0.69 suggests a good fit of the model to the data. Moreover, as can be seen from the VECM estimated Equation 4 and Table 10, that the adjustment parameter is significantly negative (-0.25) ensures the variables make reverse revision when the short-term diverges from the long-term equilibrium.

(5) The co-integration equation of VAR model 5, which shows the long-run correlations between the GDP in the tertiary industry (LGDPT) and infrastructure investment in transportation, post, education and health care (LTITPEH) and the VECM estimation equation, can be defined as below (the numbers in the square brackets under coefficients are the t-statistics):

The co-integration Equation 5:

$$\underset{}{LGDPT} = \underset{[-2.89018]}{0.55LTITPEH} - \underset{[0.79243]}{0.25LTX} + \underset{[3.23912]}{3.44LPP} - 31.36 \quad (19)$$

The VECM estimate of equation 5 is in Table 11:

$$D(LGDPT) = 0.07ECM(-1) + 0.83D(LGDPT(-1)) - 0.50D(LGDPT(-2)) + 0.23D(TITPEH(-1)) - 0.001D(TITPEH(-2)) - 0.17D(LTX(-1)) + 0.02D(LTX(-2)) + 1.4D(LPP(-1)) + 0.001D(LPP(-2)) \quad (20)$$

As can be seen from the co-integration Equation 5, infrastructure investment in transportation, post, education, and health care has a positive impact on tertiary industry GDP. *Ceteris paribus*, one unit change in infrastructure investment in transportation, post, education and health care (LTITPEH) will contribute positively 0.55 units change in the GDP in the tertiary industry (LGDPT). Moreover, that the coefficient of determination R^2 is 0.45 suggests a not bad fit of the model to the data. And as can be seen from the VECM estimate Equation 5 and Table 11, that the adjustment parameter is significantly positive (0.069816) indicates that the variables cannot make reverse revision when the short-term diverges from the long-term equilibrium.

Table 11: VECM5 (D(LGDPT), D(LTITPEH), D(LTX), D(LPP)) estimate results

Error Correction	D(LGDPT)	D(LTITPEH)	D(LTX)	D(LPP)
CointEq1	0.069816 [1.13709]	0.069816 [-1.13251]	0.092552 [0.53473]	0.110530 [3.65253]
D(LGDPT(-1))	0.832568 [3.56865]	1.492572 [2.05188]	1.027361 [1.56213]	-0.216152 [-1.87982]
D(LGDPT(-2))	-0.502272 [-1.97179]	0.878108 [1.10561]	-0.868254 [-1.20914]	-0.047962 [-0.38203]
D(LTITPEH(-1))	0.228589 [2.61679]	0.223808 [0.82172]	0.379570 [1.54140]	0.007130 [0.16561]
D(LTITPEH(-2))	0.228589 [-0.01227]	0.223808 [-0.81341]	0.379570 [-0.33553]	0.007130 [-0.36633]
D(LTX(-1))	-0.174184 [-1.65040]	-0.169154 [-0.51404]	-0.029450 [-0.09899]	0.005035 [0.09679]
D(LTX(-2))	0.015427 [0.14933]	-0.091799 [-0.28499]	-0.004291 [-0.01473]	-0.036646 [-0.71972]
D(LPP(-1))	1.381632 [3.12519]	1.026795 [0.74491]	1.807537 [1.45038]	-0.174175 [-0.79936]
D(LPP(-2))	0.001092 [0.00214]	0.131017 [0.08250]	-0.531409 [-0.37010]	0.035305 [0.14063]
R-squared	0.442686	0.382241	0.247476	0.404537
Log-likelihood	49.59382	16.61591	19.53909	70.11195

Sample period: 1978-2009

5.2.3 Granger Causality Test

The co-integration equations only show long-term equilibrium correlation between infrastructure investment and economic growth, but they do not show the direction of these relationships. Therefore, infrastructure improvements may promote economic growth, or economic growth may drive up infrastructure investment. In order to specify the relationship between infrastructure investment and economic growth, we next will employ Granger causality test to determine whether the direction between them is positive, reverse, or both.

Test results in Table 12 reveal that the total infrastructure investment (LTSBI) is a Granger cause of the GDP (LGDP), while the GDP (LGDP) is not a Granger cause of the total infrastructure investment (LTSBI). The infrastructure investment in agriculture (LTIA) is a Granger cause of the GDP (LGDP), while the GDP (LGDP) is not a cause of the infrastructure investment in agriculture (LTIA). The infrastructure investment in mining (LTIM) is a cause of the GDP (LGDP), while the GDP (LGDP) is not a cause of the infrastructure investment in mining (LTIM). The infrastructure investment in transportation, post, education, and health care (LTITPEH) is a cause of the GDP (LGDP), while the GDP (LGDP) is not a cause of the infrastructure investment in transportation, post, education and health care (LTITPEH). The infrastructure investment in agriculture (LTIA) and the GDP in primary industry (LGDPP) have mutual causality relationship between each other. The infrastructure investment in mining (LTIM) and the GDP in secondary industry (LGDPS) have no causality relationship between each other. The infrastructure investment in transportation, post, education and health care (LTITPEH) and the GDP in the tertiary industry (LGDPT) have mutual causality relationship between each other.

Table 12: Granger causality test results

Model	Null Hypothesis	X^2	P- value	Results
Y1	LTSBI does not Granger cause LGDP	3.5369	0.0316	Refuse
	LGDP does not Granger cause LTSBI	9.7528	0.2080	Accept
Y2	LTIA does not Granger cause LGDP	2.9135	0.0233	Refuse
	LGDP does not Granger cause LTIA	0.2458	0.8844	Accept
	LTIM does not Granger cause LGDP	5.4220	0.0665	Refuse
	LGDP does not Granger cause LTM	1.6996	0.4275	Accept
	LTITPEH does not Granger cause LGDP	17.6220	0.0001	Refuse
	LGDP does not Granger cause LITITPEH	3.0016	0.2230	Accept
Y3	LTIA does not Granger cause LGDPP	4.3036	0.0473	Refuse
	LGDPP does not Granger cause LTIA	5.7843	0.0230	Refuse
Y4	LTIM does not Granger causeLGDPS	3.5553	0.1690	Accept
	LGDPS does not Granger cause LTIM	2.4928	0.2875	Accept
Y5	LTITPEH does not Granger cause LGDPT	9.4641	0.0088	Refuse
	LGDPT does not Granger causeLTITPEH	6.2709	0.0435	Refuse

Note: We reject the null hypothesis when p-value is less than 5%.

Sample period: 1978-2009

Clearly, although there's no causality relationship between the infrastructure investment in mining (LTIM) and the GDP in secondary industry (LGDPS), total public infrastructure investment, public infrastructure investment in agriculture, mining, transportation, post, education, and health care all can be seen as the Granger causes of aggregate output. Thus it indicates that the variables employed in these models are reasonable Therefore, Table 12 indicates that in general infrastructure investment preceded economic growth, as Granger causality suggests.

6. Conclusions, Suggestions and Outlooks

6.1 Conclusions

Based on the time series data of aggregate output, industrial output and public infrastructure investment in China during 1978-2009, with empirical techniques such as ADF test, VAR and VECM model, co-integration test and the Granger causality test, this paper investigates the relationship between the Chinese public infrastructure investment and economic growth, controlling other critical variables such as the employed population and total import and export volume. From these analyses, we can draw the following conclusions:

(1) Total public infrastructure investment has a unidirectional, long-term, significant positive impact on aggregate output. *Ceteris paribus*, one unit change of public infrastructure investment will contribute positively 0.24 units change in GDP. Thus, obviously, public infrastructure investment in China is an efficient impetus to economic growth, especially in face of a sagging global economy.

(2) Except in agriculture, infrastructure investment in mining, transportation, post, education, and health care all have unidirectional, long-term, significant positive

impact on aggregate output. By intuition, these findings are not surprising, given the infrastructure investment situation in China. Due to geographical and topographical disparity of arable lands and regional discrepancy in agriculture production mechanization, efficiency of utilizing agriculture infrastructure is uneven across the country; therefore, the negative effect of agricultural infrastructure investment on output in some areas will offset the positive effect in the others. The positive effect of the other infrastructure investment on aggregate output serves as strong indicator of the role of infrastructure investment in promoting China's economic growth, thanks to their high output elasticity and positive externalities. And the result shows that infrastructure investment in transportation, post, education, and health care has the highest efficiency (output elasticity of 0.79), which indicates that the development of transportation, post and education, health care are contributing more to economic growth in China.

(3) As to the industry-specific public infrastructure investments, they all have long-term positive impact on corresponding industry output. An increase of one unit of investment in agriculture will contribute positively 0.32 units change in primary industry output; an increase of one unit of investment in mining will contribute positively 0.31 units change in secondary industry output; and an increase of one unit of investment in transportation, post, education, and health care will contribute positively 0.55 units change in the tertiary industry output. These results suggest that infrastructure investments in these industries are all beneficial to the development of these corresponding industries.

(4) Regarding Granger causality correlations in these models, in the long-term, total public infrastructure investment, infrastructure investment in agriculture, mining, transportation, post, education, and health care are all the Granger causes of the economic growth. Infrastructure investment in agriculture, transportation, post,

education, health care all have mutual causal relationship with their corresponding industry, respectively. However, infrastructure investment in mining has no causal correlations with the secondary industry output. This is possibly caused either by insufficient data or an implicit third-party factor or variable unknown so far.[24]

6.2 Suggestions

From a policy perspective, the fact that infrastructure investment contributes positively to economic growth in China suggests that more infrastructure investment could be beneficial. However, the smaller output elasticity in China (0.24), compared with other developing countries (1.00) (according to World Bank, 1994), makes this suggestion less attractive. The smaller output elasticity may result from the fact that China's infrastructure development, already important though, still lags behind the economy's growth rate and thus becomes a bottleneck. If infrastructure was able to satisfy the needs of a fast-growing economy, it would have played a more important role in promoting economic growth. Thus, Chinese government should continue to invest in infrastructure at a relative high level. The other possible reason of the smaller output elasticity is the low efficiency in capitalizing infrastructure investment, since Chinese enforcement of such investment is famous for corruption and inefficiency. Thus, Chinese government should devote more effort to infrastructure investment enforcement and to anti-corruption policies.

Moreover, infrastructure investment structure needs to be optimized. Empirical test results show that the magnitude of effects of infrastructure investment on economic growth differs across industries. Infrastructure investment in transportation, post, education, and health care contributes the most to economic growth, while

[24] Candidates of these unknown factors include corruption or natural monopoly in this industry.

infrastructure investment in mining takes the second place. Therefore, Chinese government should invest more in bottleneck industries such as insufficient transportation facilities, long-term energy supply and so on.

Additionally, results show that industry-specific infrastructure investment have positive effect on all corresponding industries, suggesting that to promote industrial development, Chinese government should not neglect any industry, even the one with lowest output elasticity or negative effect on aggregate output, i.e. agriculture.[25]

6.3 Outlook

Over the past decades, China has undergone a profound social and economic change. These changes, such as in structural data collection mechanism, region heterogeneity or efficiency of government departments, may all have potentially important effect on economic growth. Given these situations, future research could be conducted on the following aspects. First, structural change should be captured by adequate models. Second, partitioned data should be used to investigate change in policy and data collection standard. Moreover, considering the vastness of China and its diversity in geography and economy, a panel approach could also be adopted to incorporate the heterogeneity across regions. In addition, China's centralized political constitution necessitates studies that investigate the effect of the government's bureaucratic quality on the efficiency of infrastructure investment.

[25] Another reason that agriculture cannot be sacrificed is its important role in the society's sustainability. Farm labors constitute a large percentage in the country's labor force. A shrinking agriculture sector will aggravate China's unemployment problem and undermines its international independence in food supply, thus endangering its national security.

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