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Investment efficiency of urban infrastructure systems: Empirical measurement and implications for China

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ABSTRACT

Infrastructure investment is vital to a nation's long-term development and its performance needs to be carefully evaluated to ensure the effectiveness, efficiency, and equity of infrastructure decisions. Though some studies attempt to evaluate the development level of infrastructure systems, most of them focus on economic influence but neglect other aspects such as societal benefits. To advance the accuracy of the current method, we expanded a multi-attribute evaluation framework based on a data envelopment analysis (DEA) based Malmquist productivity index (MPI) to evaluate the longitudinal efficiency of China's infrastructure investment. The statistical data from 2004 to 2014 in 30 provincial-level administrative divisions were collected as inputs and outputs of the model for a dynamic cross-provincial comparison. We found that, firstly, the overall efficiency of infrastructure investment during the study periods was improved by 2.4% and the increase was primarily due to technical change rather than efficiency change. Secondly, an uneven distribution of the efficiency level existed among different regions, with the eastern region as the best performance of an average MPI of 1.067 and the western region being the lowest. Thirdly, each provincial-level administrative division exhibited a distinctive changing profile over the period, with Beijing (20.5%) and Shanghai (20.4%) as the fastest growing provinces yet Shandong the slowest (−13.1%). The yearly change, its interpretation and in-depth analysis of MPI's decomposition have also been discussed. The proposed approach and findings can provide insights for making long term investment strategies and infrastructure policies in China and similar countries.

1. Introduction

The well-developed urban infrastructure systems are considered as the physical structure for societal operation and the foundation for urban sustainable development (Czernich, Falck, Kretschmer, & Woessmann, 2011). The term "infrastructure" involves three parts, including public works (such as roads, canal works for irrigation), public utilities (such as telecommunications, power, piped gas and water supply, sanitation and sewerage, and solid waste collection and disposal), and other transport sectors (such as railways, airports, urban transport, and ports) (World Bank, 1994). The growth of infrastructure projects in developing countries significantly contributes to the prosperity and advancement of these countries.

In China, accelerated economic growth and urbanization have produced unprecedented demands on infrastructure development over the past few decades. Infrastructure development has become the main concern for the Chinese government as a key economic stimulus initiative formalized in regular National Five-Year Plans. In November 2008, China proclaimed an enormous stimulus package of RMB 4 trillion (around USD 585 billion) to revitalize the national economy after the global recession. Thereinto, RMB 1.5 trillion was invested in urban infrastructure.

However, the value of infrastructure investment can be fully realized only when the investment is well planned and fulfilled appropriately. Adversely, the irrational infrastructure investment decision may result in inefficiency and resource waste that not only hinder the urban development, but also arouse intractable social issue (Castells & Solé-Ollé, 2005). How to evaluate and improve the infrastructure investment efficiency has become a major focus of the Chinese government (Liu, Wang, Zhang, Li, & Zhao, 2017). Efficiency is defined as the quality of doing something well and effectively without waste (The Longman Dictionary). In academic research, efficiency is typically quantified as the ratio of the generated outputs to the inputs (Egilmeza & McAvoyc, 2013). This concept has been widely used to assess the performance of urban infrastructure, such as the efficiency of sustainable infrastructure projects in China (Zhang, Wu, Skitmore, & Jiang, 2015) and the efficiency of rail network system in Western Europe (Smith, Wheat, & Smith, 2010). We followed the

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similar definition by referring infrastructure investment efficiency to producing the most outputs (such as urban economic growth and social development) from the least amount of inputs (such as invested infrastructure). To study on the investment efficiency is critical to understand the effectiveness of infrastructure decision-making and can provide a rationale for future infrastructure policies.

The objective of the research is to comprehensively measure the China's infrastructure investment efficiency and its changing patterns during the period of 2004–2014. Meanwhile, the regional development in China is unbalanced, and infrastructure investment is also diversified in different regions. In this study, we assessed and compared the infrastructure investment efficiency of 30 provincial-level administrative divisions in China based on the DEA-based MPI model. The results of this study can enrich the evaluation method of infrastructure investment efficiency, thus providing an additional tool for the administration to design prominent infrastructure policies.

The rest part of this study is organized as follows. In the following section, we reviewed the current literature on infrastructure investment and the DEA-based MPI model. Then, the DEA-based MPI model was introduced to evaluate infrastructure investment efficiency. Followed by that, we selected input and output factors required by the model, measured the infrastructure investment efficiency based on empirical data, and discussed the results. Lastly, conclusions and managerial implications were presented.

2. Literature review

Many scholars have paid attention to the study of infrastructure investment. Existing studies on the infrastructure investment measurement focus mainly on economic return of investment. Since the pioneering work by Aschauer (1989a), the relationship between infrastructure investment and economic growth have been investigated by several scholars (e.g. Esfahani & Ramirez, 2003; Farhadi, 2015; Hashimzade & Myles, 2010; Kayode, 2013; Sahoo & Dash, 2012). One common method is to estimate the production function by setting infrastructure as an input variable. Several scholars found a significant correlation between infrastructure investment and returns (e.g. Aschauer, 1989b; Munnell, 1990; Munnell, 1992), while others did not find such a correlation (e.g. Kavanagh, 1997; Tatom, 1991). Another used method is the cost function. Based on this method, Morrison and Schwartz (1996) evaluated the contribution of infrastructure to firms' costs and productivity growth. In addition, some scholars use vector autoregression (VAR) (e.g. Annala, Batina, & Feehan, 2008; Herranz-Loncán, 2007) and vector error correction model (VECM) (e.g. Pradhan & Bagchi, 2013) to analyze the impact of infrastructure investment on the economic growth. So far, several studies focusing on China's infrastructure development have concluded a positive relationship between infrastructure and economic growth (e.g. Démurger, 2001; Fan & Zhang, 2004; Guo & Xia, 2011; Shi & Huang, 2014).

Although some scholars discussed the impacts of infrastructure investment on regional economic growth, few focused on the evaluation of nationwide infrastructure investment efficiency. Among those studies on the assessment of infrastructure investment, most of them only examined the economic effect of infrastructure investment while neglecting the other dimensions, such as societal benefits and urban system development. In fact, infrastructure not only affects economic growth, but also creates changes in non-economic aspects such as technology, society, and environment. Thus, the assessment of the infrastructure investment efficiency should consider both economic and non-economic factors, regarding as an issue with multiple inputs and outputs.

DEA, which was presented by Charnes, Cooper, and Rhodes (1978) and extended by Banker, Charnes, and Cooper (1984), is a suitable method to assess the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs. In DEA method, linear programming technique is used to find an efficient frontier or best-practice without a priori information on tradeoffs among inputs and outputs. The DMUs with minimum input levels given output levels or with maximum output levels given input levels form the DEA frontier (Chen & Ali, 2004). DEA has been commonly used for many areas of efficiency measurement for the following benefits (Chen, 2003; Lee & Pai, 2011; Yun, Nakayama, & Tannino, 2004; Zhu, 2002). Firstly, it can be applied to measure the relative efficiency with no need for previously knowing the functional form between inputs and outputs. Secondly, DEA can evaluate multiple inputs and multiple outputs with no requirement for pre-assigned weights. Finally, DEA models incorporate decision maker's preferences.

Färe, Grosskopf, Lindgren, and Roos (1992, 1994b) further proposed a DEA-based Malmquist productivity index (MPI) that can evaluate the change of DMUs' efficiency during a period. DEA-based MPI has been used in various industries such as manufacturing, banking and semiconductor. For example, Mahadevan (2002) used it to analyze the productivity growth performance of Malaysia's 28 manufacturing industries from 1981 to 1996. Chen (2003) further extended the DEA-based MPI and applied it to computer companies. Asmild, Paradi, Aggarwall, and Schaffnit (2004) combined DEA window analysis with the MPI to analyze Canadian banking industry's development from 1981 to 2000. Liu and Wang (2008) adopted the DEA-based MPI model to assess the productivity of semiconductor packaging and testing firms in Taiwan from 2000 to 2003. Chiang, Li, Choi, and Man (2012) applied this method to analyze the efficiency of 24 construction companies of China mainland and China Hong Kong from 2004 to 2010. Egilmeza and McAvoyc (2013) employed the model to measure the efficiency of U.S. States in reducing road fatalities.

MPI was introduced to generate DEA efficiency scores based on the regression analysis and long-term panel data. It can be disintegrated into two components, the technical efficiency change and the technology frontier change between two periods. It can help us to further analyze the reason for the change of efficiency. Since infrastructure investment has the time lag effect on urban development, it will be meaningful to analyze the historical change of investment efficiency. The DEA-based MPI model is well suited for evaluating the efficiency change of infrastructure investment. However, existing studies for DEA-based MPI have mainly focused on the corporate level or limited to certain industries. There are a few relevant literature on the single infrastructure sector, such as transportation (Maroto & Zofío, 2016; Örkcü, Balıkçı, Dogan, & Genç, 2016), water treatment (Molinos-Senante, Hernández-Sancho, & Sala-Garrido, 2015) and energy (Munisamy & Arabi, 2015), but not focusing on the integrated assessment of the whole infrastructure investment in a region. This study can enrich the extant knowledge of infrastructure system by extending the applicability of DEA-based MPI method for multi-regional infrastructure development so as to suggest insightful investment strategies for the long-term infrastructure planning.

3. DEA-based Malmquist index

DEA computes the relative efficiency of DMUs with many inputs and outputs based on linear programming and production theory. The DMUs found to be on the efficiency frontier are the most efficient, and a DMU's position relative to the efficiency frontier is used to measure its efficiency (Chung, Pearn, & Lee, 2006). The Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) models are the most popular models of DEA. CCR was proposed by Charnes et al. (1978) to compute the efficiency in ratio form by supposing constant returns to scale (CRS) (Chung, Lee, Kang, & Lai, 2008). Banker et al. (1984) introduced a BCC model by assuming variable returns to scale (VRS). Under CCR, a doubling of all inputs leads to a doubling of all outputs, while under VRS, a doubling of all inputs may lead to either more or less than a doubling of all outputs (Lee, Kang, & Lin, 2015).

Assume there are n DMUs, each DMU$_j$ ($j = 1,2, \cdots n$) generates a