A regional and provincial productivity analysis of the Chinese construction industry: from 1995 to 2012

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Abstract

The Chinese construction sector is one of the largest in the world, but the nation's 31 provinces, autonomous regions, and municipalities (hereafter 'provinces' for simplicity) have experienced varying levels of economic development. It is important for stakeholders to truly understand Chinese construction sector efficiency and these disparities. Considering it a more robust approach, this study uses the Färe-Primont data envelopment analysis (DEA) method to estimate construction productivity and efficiency across China from 1995 to 2012. A general finding is that construction productivity in China has experienced incredible growth from a low base in 1995, with Eastern China the most productive region and Northern China the least. The most productive provinces were Zhejiang, Hunan and Jiangsu; contradicting conventional wisdom, the least productive were Beijing, Shanghai and Guangdong. Decomposing the productivity further, it is found that China's construction industry appears to be more scale-efficient than technically efficient. In other words, the industry is operating at an optimal scale for productivity but relies less on technological advancement. This research provides significant insights for understanding productivity of the world's largest construction market in a different perspective. The Färe-Primont DEA method appears to be an effective means of probing industry efficiency from different perspectives, and enables development of evidence-based policies targeted at improved construction productivity in particular regions or provinces.

Keywords: Construction, productivity, China, Färe-Primont data envelopment analysis

Introduction

According to Asia Construction Outlook (2013), China's construction spending in 2012 reached US$1.25 trillion, contributing 41 percent of construction spending in the Asia-Pacific region and 19 percent of China's GDP. The National Bureau of Statistics of China (NBSC) (2013) estimates the direct contribution of construction to total GDP in 2012 to be somewhat lower at 6.8 percent and 3549.1 billion yuan (1 USD≈6.5 yuan in 2015). China thus probably has the largest construction market in the world. As in the West, construction in China is a 'pillar' industry, which not only materialises the built environment, but also boosts the economy and provides job opportunities (Lu et al. 2008). For example, in the face of the 2008 Global Financial Crisis, the Chinese government launched a 4 trillion yuan stimulus package, most of which was channelled into development of railways, roads, and other infrastructure. Understanding the productivity and efficiency of China's massive construction industry is important to not only prospective foreign investors, but also those interested in the past, present, and future of this industry.

Productivity is a fundamental indicator of economic efficiency, growth, competiveness and progress. It is a basic analytic tool used in economics and management, since any increase in productivity indicates that scarce and expensive human and material resources are used more efficiently. Xue et al. (2008) argue that while productivity is not the only determinant of economic growth, it does provide a measure of economic prosperity and of industry competitiveness. Lall et al. (2002) add that productivity analysis can provide valuable information about the effectiveness of economic policies, and it is thus a useful policy design tool. For the purposes of this research, productivity is defined as a ratio of aggregate output to aggregate input, and productivity estimates are decomposed into construction industry sector measures.

China's geographical imbalances are central to understanding its construction industry. In particular, economic development and construction spending have historically been concentrated along the eastern seaboard. These have led to regional imbalances in terms of construction productivity. Xue et al. (2008) measured construction industry productivity at regional level from 1997 to 2003, finding gaps in productivity development level among the western, central, eastern, and northeastern regions. At provincial level, Wang et al. (2013) measured total factor productivity (TFP) of the construction industry in China's thirty-one provinces from 2006 to 2010, detecting obvious 'spatial differences'. The NBSC also annually publishes overall labour productivity in terms of value-added and total output value at province level. Wang et al. (2013) point out that long-standing and increasing imbalances not only hinder effective resource distribution but also influence total productivity of China's construction industry. This is further complicated by the huge size and massive population of China, its ongoing transition from a centrally planned to market economy, and its increasing integration into the global community (Ling et al. 2005; Lu et al. 2012).

Beyond mere reporting of provincial imbalances in construction productivity, one needs to probe the causes of these imbalances, as Balk (2001) suggested that the explanation of productivity change is greatly facilitated if we are able to decompose any measure of it into meaningful, preferably independent factors. Specifically, a question is asked whether the technical or scale efficiency of particular provinces is a key factor. For the purposes of this research and referring to Farrell (1957), technical efficiency is defined as the ability of a construction industry for a given province to obtain maximum output from a given set of inputs. By referring to Balk (2001), scale efficiency is defined as the ability of the construction industry for a given province to operate at an optimal scale. The role of scale efficiency for interpreting productivity has been increasingly recognized and measured (e.g. Nemoto and Goto, 2005). A unit is said to be scale efficient when its size of operations is optimal so that any modifications on its size will render the unit less efficient (Coelli et al., 2005). This is known as 'scale of economy' in economics term. It is understandable that a unit, a company, or a province's construction companies will perform more productive at an optimal scale, which may be a result of natural market choice or deliberate institutional arrangement. Certainly, technical efficiency and scale efficiency by nature could be intertwined.

Reviewing the literature on measuring productivity in China's construction industry, most studies are found to use a Malmquist-based data envelopment analysis (DEA) approach to estimate productivity and produce efficiency estimates. A critique of productivity estimate approaches will be provided later; for now, however, it is argued that the Färe-Primont DEA method is preferable to the Malmquist DEA approach (O'Donnell 2011). The Färe-Primont index can be exhaustively decomposed into input- and output-oriented measures, enabling a more detailed understanding of construction productivity. It also satisfies index number theory and economically relevant axioms while the Malmquist, Fisher, Törnqvist and other commonly used indexes often fail to satisfy. Moreover, by optimizing the construction inputs and outputs, better estimates can be achieved. This allows improved understanding of construction productivity in terms of efficiency in the sector, at various provincial and regional levels, and over time.

It is thus the aim of this study to conduct an alternative regional and provincial productivity analysis of the Chinese construction industry, with a view to advancing understanding of the industry as well as the methodology for measuring construction productivity. This paper begins with a review of construction literature, with particular interest given to productivity studies of the Chinese construction industry. The methodological techniques applied, input and output data items, and duration of data are discussed as these differences are likely to be reflected in productivity and efficiency findings. In particular, we consider change in building floor space as a measure of output quality from the perspective that larger floor space requires increased labour and capital intensity and provides a basic indication of quality change over time. The next section outlines the Färe-Primont DEA-based total factor productivity methodology used in this paper to estimate productivity and efficiency, as well as the data which comprises multiple construction inputs and outputs for the thirty-one Chinese provinces from 1995 to 2013. Productivity and efficiency results are presented and analysed in the results section. Finally, based on the research results, conclusions and future research directions are discussed.

Review of the literature

Malmquist DEA versus Färe-Primont DEA

The basis for productivity estimation in this research is data envelopment analysis (DEA), a data-oriented method for measuring the relative efficiency of decision-making units performing similar tasks in a production system (e.g. a province's construction sector) that consumes multiple inputs to produce multiple outputs (Charnes et al. 1978). Essentially, the analysis uses linear programming methods to construct a nonparametric frontier over aggregated input and output data (Coelli et al. 2005). The efficiency measures are then calculated using the distances between data points and the frontier. As highlighted by Xue et al. (2008), DEA has advantages in that it can analyse multiple inputs and multiple outputs without pre-assigned and controversial weights, measure relative efficiency based on the observed data without prior knowledge relating to the production function, and incorporate decision-makers' preferences. The application of DEA for productivity and efficiency estimation was pioneered by Charnes et al. (1978) based on the previous work of Debreu (1951) and Farrell (1957). Decomposition of DEA productivity indexes for efficiency estimation was further developed by Fried et al. (1993), who noted the importance of productivity decomposition and its detailed understanding in policy-making. While DEA has become a leading productivity and efficiency tool amongst researchers, traditional methods such as the Tornqvist index and chained binary indexes continue to be used by official statistical agencies globally.

DEA has become a popular method for productivity estimation and decomposition, and the majority of these studies use the Malmquist index (Caves et al. 1982).The Malmquist-based DEA approach has been widely adopted by studies estimating productivity and efficiency in the Chinese construction industry. For example, Wang et al. (2013) analyse regional productivity and efficiency in the Chinese construction industry from 2006 to 2010 using a Malmquist-based DEA total factor productivity (TFP) approach; Xue et al. (2008) use a similar approach for the years 1997 to 2003. According to Bjurek (1996), the Malmquist approach has become standard for productivity estimation. While acknowledging the popularity of the Malmquist index, O'Donnell (2012) specifies that, in general, it should not be used to measure TFP change as it is not additively or multiplicatively complete, and also that the Malmquist TFP index cannot always be decomposed into measures of efficiency in an economically meaningful way. For example, Färe et al. (1994) notes that decomposition of the Malmquist TFP index usually results in biased estimates of technical and efficiency change.

The Färe-Primont DEA method as proposed in O'Donnell (2011), using a multiplicatively complete index, has also been adopted by researchers estimating productivity. While not specific to the construction industry, Laurenceson and O'Donnell (2014) use this method to estimate productivity for China's provinces from 1978 to 2010, detailing its advantages over the Malmquist index approach. The first is that the Färe-Primont index can be exhaustively decomposed into input- and output-oriented measures of technical change, technical efficiency change, scale efficiency change and mix efficiency change, allowing for an explicit interpretation of theoretical concepts. Laurenceson and O'Donnell (2014) emphasize the importance of being able to differentiate between technical and scale efficiency in an applied public policy environment, given that different policies are needed to address them. The second fundamental advantage of the Färe-Primont method is that it satisfies index number theory and economically relevant axioms, including the transitivity axiom, which most commonly used indexes such as the Malmquist, Fisher and Törnqvist indexes fail to do so (O'Donnell, 2014). Indexes that fail the transitivity axiom cannot be used to make reliable productivity comparisons where there are more than two observations (Laurenceson and O'Donnell 2014). As the research reported in this paper uses multiple input and multiple output construction data for China's thirty-one provinces from 1995 to 2012, use of the Färe-Primont method is important for obtaining reliable productivity and efficiency estimates.

The advantages of the Färe-Primont index over the Malmquist DEA approach are beginning to be recognised. Nguyen and Simioni (2015) estimate productivity and efficiency of the Vietnamese banking system using the Färe-Primont DEA approach. Rahman and Salim (2013) use the Färe-Primont method in O'Donnell (2012) to estimate agricultural productivity for Bangladesh from 1948 to 2008; Widodo et al. (2014) to estimate Indonesian manufacturing industry productivity, noting the benefits of this relatively new index-based method. Several studies using the Färe-Primont DEA method to estimate construction productivity have been identified. For example, Chancellor and Abbott (2015) apply the method to estimate construction productivity in Australia, while Chancellor et al. (2015) estimate productivity and efficiency of the Australian and New Zealand construction industries at a regional level. However, this study is the first known example of Färe-Primont method application to estimating construction productivity and efficiency in the China context.

Inputs and outputs for measuring productivity

Productivity is nothing other than the relationship between the production of a good or service and the factors of production used. Kendrick (1956) states that "The story of productivity, the ratio of output to input, is at heart the record of man's effort to raise himself from poverty". The inputs and outputs used for measuring construction productivity, however, vary from one study to another and thus likely result in differing productivity and efficiency findings. To reflect a more comprehensive view of efficiency, total factor productivity (TFP) has gradually replaced single factor productivity (e.g. labour productivity) in academic studies. However, the latter is still widely adopted by official statistics agencies. Kendrick (1970) classifies inputs into two main categories: tangible (e.g., labour, capital) and intangible (such as expenditures in R&D and education). Using TFP, Chau and Walker (1988) adopt gross output as the output variable and four components (labour, materials, plant and equipment, and overheads) as input variables in conducting an empirical study of the construction industry in Hong Kong. In Wang et al. (2013), regional-level construction inputs used are total assets of construction enterprises, number of construction industry employees, and total power of machinery and equipment owned; outputs are construction industry value added and gross output value. Using two inputs (assets and employees) and one output (value added), Xue et al. (2008) find overall construction productivity growth in China from 1997 to 2002, followed by a period of decline from 2002 to 2003.

TFP inputs should use at least some measure of capital and labour as demonstrated in Chau and Walker (1988), Chen (2003), and Xue et al. (2008). It is possible to expand the range of inputs to include energy, material inputs and purchased services, for example. Usually, some form of construction value added (Chen 2003; Xue et al. 2008) or gross construction output such as total building work completed (Chau and Walker 1998), is applied as a single output. These additional outputs can be aggregated into a single output category as outlined in Coelli et al. (2005). The use of multiple inputs and multiple outputs in estimating construction TFP is demonstrated by Chancellor et al. (2015). To the extent that the data is available this is often advisable so that the main aspects of the production process are accounted for. The most fundamental TFP studies, however, typically use two inputs (labour and capital) and one output (value added), thereby not necessarily capturing all elements of the production process. In addition to labour and capital construction inputs, it is possible to include total power of machinery and equipment, an often overlooked element in the TFP estimation process. Similarly, the inclusion of constructed floor space as a second output alongside industry value added means that the production process can be recognised as more than a simple value and allows consideration of the elements of size and quality.

In summary, existing studies measuring construction productivity in China have mainly adopted the Malmquist DEA approach, over which the Färe-Primont DEA method has various advantages. It can be exhaustively decomposed into input- and output-oriented measures allowing for an explicit interpretation of theoretical concepts, and it also satisfies index number theory and economically relevant axioms. Therefore, there is scope for revisiting construction productivity at regional and provincial levels in China using the Färe-

Primont DEA method, with a view to providing an alternative or even better understanding of Chinese construction industry efficiency. In addition, the input and output factors should be carefully considered in measuring productivity, which is a ratio of output to input *per se*.

Data and methodology

Though a complex task, input and output data items from 1995 to 2012 across China's thirty-one provinces were obtained. To the best of the authors' knowledge, this is the most extensive time series available for provincial analysis of total factor productivity (TFP) of the Chinese construction industry. Data for all provinces was derived from China Statistical Yearbooks for the time period 1995 to 2013 with the exception of Chongqing, a direct-controlled municipality for which data is only available since its establishment in 1997. The dataset contains two output variables and four input variables specific to the construction industry for all thirty-one provinces. The output variables used were 'Total floor space of buildings completed (10,000 meters squared)' and 'Total output value of construction (10,000 yuan)'. As discussed previously, the inclusion of floor space of individual apartments is important as it enables measurement of output quality beyond value. Floor space has been used previously as a quality adjustment factor for productivity estimation in Rosefielde and Mills (1979). They found that conventional productivity adjustments did not sufficiently account for changes in quality in their study of the American construction industry, considering floor space as a suitable adjustment method. Without this variable, quick construction of small, simple buildings could result in perceived high productivity growth. Furthermore, in their study of the Chinese construction industry, Yung and Yip (2010) found that construction quality tends to be higher for buildings with larger floor space. Ideally the use of quality adjustment variables for both building construction and engineering construction would be included however due to data limitations this was not possible. We consider the use of partial quality adjustment to be beneficial in understanding the Chinese construction industry from a perspective not previously considered. The input variables were 'Number of construction workers and staff at year end', 'Paid up total capital (10,000 yuan)', 'Total assets (10,000 yuan)' and 'Total power of machinery and equipment owned (10,000 kilowatts)'. The dataset contains 108 data points (18 year*6 inputs and outputs=108) for each province (except for Chongqing, which was only available for sixteen years and therefore has 96 data points), and the analysis used a total of 3,532 data points.

To start, Equation (1) defines construction TFP of a province as a ratio of multiple outputs to multiple inputs. As outlined in O'Donnell (2008), the input and output quantity vectors of province i in period t are respectively defined as $x_{it} = (x_{1it}, \dots, x_{kit})'$ and $q_{it} = (q_{1it}, \dots, q_{kit})'$:

$$TFP_{it} = \frac{Q_{it}}{X_{it}} \qquad (1)$$

where k is the total period of t, and also the number of data points.

To define TFP as an index, aggregate output is $Q_{it} = Q(q_{it})$, and aggregate input is $X_{it} = X(x_{it})$. As outlined in O'Donnell (2011), Q_{it} and X_{it} are non-negative, non-decreasing and linearly homogeneous aggregator functions. The TFP index of province *i* in period *t* relative to TFP of province *h* in period *s* is:

$$TFP_{hs,it} \equiv \frac{TFP_{it}}{TFP_{hs}} = \frac{Q_{it}/X_{it}}{Q_{hs}/X_{hs}} = \frac{Q_{hs,it}}{X_{hs,it}} \qquad (2)$$

Equation 2 presents TFP as a measure of output growth divided by input growth where $Q_{hs,it= Q_{it}/Q_{hs}}$ is an index of output quantity and $X_{hs,it= X_{it}/X_{hs}}$ is an index of input quantity. The Färe-Primont method as used in this paper relies on the Shephard (1953) input D_i and output D_o distance functions. The Shephard input distance function gives the minimum inputs while holding the outputs fixed, whereas the Shephard output distance function gives the maximum output while holding the input fixed (Shephard, 1970). These functions can be used to control input or output oriented measures of Färe-Primont DEA. For the purposes of this research, input orientation was used only. Input orientation is the most appropriate orientation for the purposes of the construction industry since the inputs tend to be the decisive variables in the construction industry, meaning that decision-makers have the most control over these variables.

The index represented in Equation (3) as first proposed in O'Donnell (2011) and also detailed in O'Donnell (2014) is the Färe-Primont index as used to estimate productivity for the Chinese construction industry in this paper:

$$TFP_{hs,it} = \frac{Q_{hs,it}}{X_{hs,it}} = \frac{D_O(x_0,q_{it},t_0)}{D_O(x_0,q_{hs},t_0)} \frac{D_I(x_{hs},q_0,t_0)}{D_I(x_{it},q_0,t_0)} \qquad (3)$$

where $Q_{hs,it} = \frac{D_O(x_0,q_{it},t_0)}{D_O(x_0,q_{hs},t_0)}$ and $X_{hs,it} = \frac{D_I(x_{it},q_0,t_0)}{D_I(x_{hs},q_0,t_0)}$. $D_0(.)$ and $D_I(.)$ refer to output and input distance functions as previously discussed.

As outlined in O'Donnell (2011), Färe-Primont DEA allows for the decomposition of TFP into various measures of efficiency. For the purposes of this research, input-oriented technical (Equation 4) and scale efficiency (Equation 5) were produced for the Chinese construction industry at a province level. Where $\tilde{Q}_{it}$ is the maximum aggregate output possible when using x_{it} to produce any output vector. $\tilde{X}_{it}$ is the minimum aggregate input possible when using any input vector to produce q_{it} . $\bar{X}_{it}$ is the aggregate input obtained when TFP is maximised subject to constraint that the output and input vectors are scalar multiples of q_{it} and x_{it}.

$$ITE_{it} = \frac{Q_{it}/X_{it}}{Q_{it}/\bar{X}_{it}} = \frac{\bar{X}_{it}}{X_{it}} = D_i(x_{it}, q_{it}, t)^{-1} \leq 1 \quad (4)$$

$$ISE_{it} = \frac{Q_{it}/\tilde{X}_{it}}{\tilde{Q}_{it}/\bar{X}_{it}} \qquad (5)$$

To practically estimate input-oriented TFP and various efficiency measures for the Chinese construction industry, the dataset was assembled into DPIN Version 3.0. This software uses a linear programming method to construct a frontier over data points as proposed by Farrell (1957), producing TFP and various measures of input- and output-oriented efficiency. Construction industry *TFP*, *ITE* and *ISE* were all calculated at the province level from 1995 to 2012. For the purposes of data presentation and discussion, province-level results were also aggregated to regions of Northern China (Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia), North East China (Liaoning, Jilin, and Heilong Jiang), Eastern China (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong), Central and Southern China (Henan, Hubei, Hunan, Guangdong, Guangxi, and Hainan), South West China (Chongqing, Sichuan, Guizhou, Yunnan and Tibet), and North West China (Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang). This categorization of provinces by region is based on that used in the China Statistical Yearbooks.

Findings and discussions

Construction productivity by regions and provinces

The Chinese construction industry experienced incredible output growth during the period measured, becoming one of the largest construction markets in the world by 2012. It is to be expected that such strong growth would be accompanied by productivity improvement and, as demonstrated in Figure 1, overall construction productivity in China indeed increased significantly from a low base in 1995. However, analyses conducted using the Färe-Primont DEA index reveal considerable regional imbalances. Stronger productivity growth was achieved by North East China, Eastern China, and Central and Southern China. Eastern China in particular appears to have sustained steady, strong productivity growth. Conversely, Northern China was found to have the lowest productivity performance of the regions, actually becoming less productive during the time series 1995 to 2012.

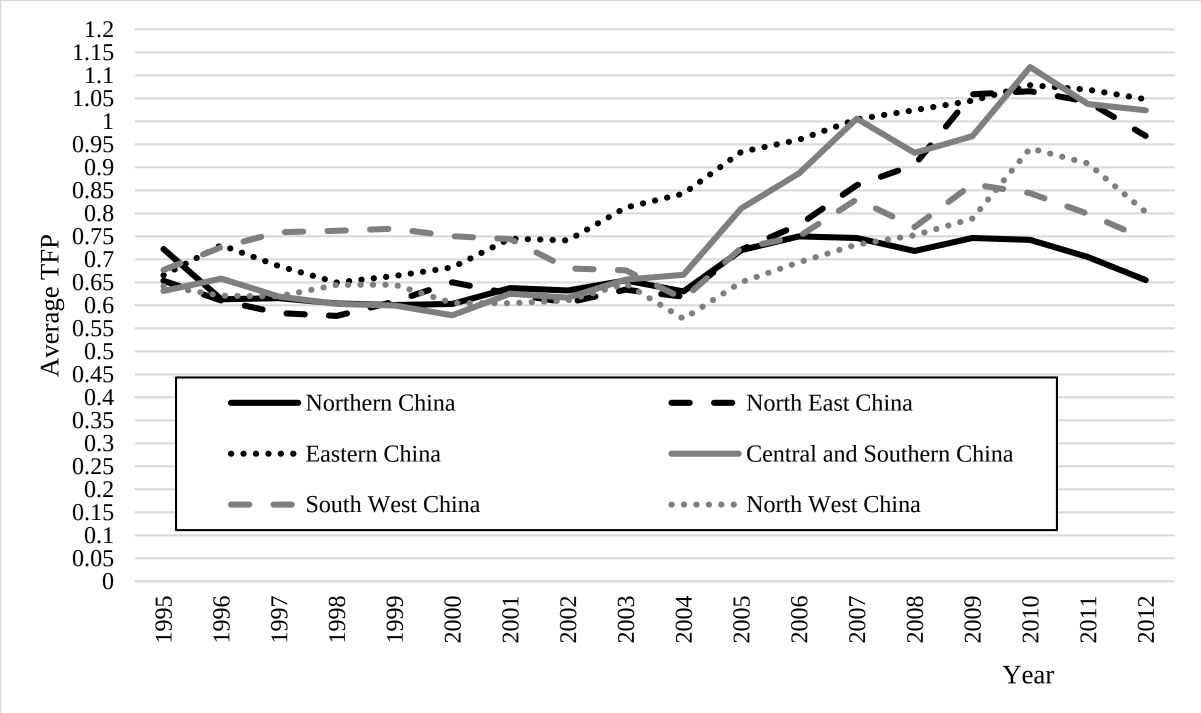

Figure 1: Construction TFP by region from 1995 to 2012

Data source: Input and output data from China Statistical Yearbooks 1996 to 2013

The regional results in Figure 1 can be further analyzed by observing the corresponding provincial-level results in Table 1. In order of appearance in the table, Northern China obtained the lowest productivity during the examined period, largely due to low productivity in the province of Beijing. This is likely to be the result of high density and small size of constructed apartments in Beijing, particularly since the productivity method used in this paper considers floor space of individual apartments as a quality adjustment of output. In the so-called tier 1 cities in China such as Beijing, Shanghai, Guangzhou, and Shenzhen, owing to the dilemma between limited land supply and compelling housing demand, co-existing with the regular apartments are a large number of apartments with smaller gross floor area (GFA). For the reasons argued in the methodology part, these smaller apartments are considered as lower quality and they undermine the overall construction productivity when quality is used as an adjustment of output. Without considering the quality adjustment, i.e. using the overall GFA in a province as an output, the construction productivity in these provinces is higher, which is consistent with the results reported by NBSC. In addition, owing to the high built-up area of space, to re-assemble lands for new building means demolition of existing old buildings, the high cost of which is counted as an input. Although this massive demolition has also been witnessed in other cities, its scale and intensive are particularly high in these high population Tier 1 cities. Similarly, Wang et al. (2013) suggest that Beijing's low construction industry TFP is due to the fact that this province is China's economic and trade hub, with a high population density and little available land for new buildings. Hebei obtained the highest productivity results in Northern China. Eastern China had the highest productivity results amongst regions, led by Zhejiang, Jiangxi, Fujian and

Jiangsu. Zhejiang was found to have the highest average productivity of all Chinese provinces from 1995 to 2012, which may be explained by the fact that this province has long been recognised as a free market economy with few institutional constraints. Shanghai obtained the lowest productivity results for Eastern China, similar to those of Beijing and likely for similar reasons: high-density construction conditions and the small size of apartments constructed.

1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
1	0.5349	0.5194	0.518	0.4783	0.4855	0.4904	0.5163	0.5204	0.3668	0.4105	0.4275	0.3875	0.3821	0.4023	0.4038	0.3863	0.3883
0.5709	0.6208	0.5911	0.5475	0.5614	0.5628	0.5937	0.5975	0.6471	0.6723	0.7168	0.7497	0.7116	0.6278	0.6651	0.6976	0.6676	0.5715
0.8082	0.7984	0.7961	0.7704	0.7548	0.7301	0.7742	0.7575	0.7692	0.6613	0.9642	0.9983	0.9373	0.919	0.9582	1.046	1.0774	1.0633
0.5778	0.521	0.5607	0.5474	0.5535	0.5397	0.5868	0.5775	0.6055	0.6586	0.7002	0.6916	0.6825	0.6988	0.7735	0.7322	0.6416	0.6205
0.6558	0.5905	0.6108	0.6379	0.6557	0.6978	0.7423	0.7137	0.7285	0.7914	0.8087	0.883	1.0132	0.963	0.9324	0.8314	0.7527	0.6314
0.6589	0.5899	0.5691	0.5435	0.5793	0.6427	0.6799	0.6648	0.7267	0.7787	0.8507	0.8783	0.8802	0.9175	0.9998	1.0492	1.1073	1.0438
0.6376	0.6013	0.5568	0.5797	0.6318	0.7122	0.6406	0.6099	0.6296	0.5618	0.7215	0.8326	1.0226	1.0948	1.298	1.1068	1.0416	0.8479
0.6642	0.6398	0.6242	0.6076	0.6141	0.5954	0.556	0.5426	0.5455	0.5159	0.5909	0.6137	0.6811	0.7042	0.8787	1.0404	0.9793	1.0134
0.6837	0.6377	0.6469	0.6012	0.5221	0.4979	0.5508	0.5224	0.5532	0.6099	0.6495	0.6469	0.6136	0.6147	0.6417	0.6181	0.5626	0.5129
0.7395	0.837	0.7811	0.7674	0.7546	0.8062	0.8435	0.8534	0.9483	0.9205	1.0197	1.0312	1.1452	1.1732	1.1948	1.2187	1.117	1.1454
0.8074	0.9589	0.8741	0.8538	0.9195	0.9771	1.0925	1.1895	1.2676	1.3659	1.3492	1.3664	1.3993	1.4374	1.4298	1.4045	1.4211	1.4348
0.6776	0.8384	0.8176	0.7087	0.7458	0.7219	0.7944	0.7374	0.7992	0.85	0.9271	0.94	0.9522	0.9697	0.955	0.9789	0.9946	0.9561
0.534	0.5114	0.4839	0.4492	0.4548	0.4622	0.6149	0.554	0.6473	0.6501	0.8333	0.9442	1.0727	1.083	1.0848	1.2112	1.2663	1.2361
0.5983	0.5914	0.4892	0.4825	0.5342	0.582	0.6149	0.6553	0.775	0.8151	0.9655	1.0156	1.058	1.0991	1.195	1.2961	1.3472	1.3025
0.6173	0.7404	0.7028	0.6852	0.7167	0.7286	0.7035	0.6755	0.6967	0.6894	0.7899	0.7762	0.7901	0.7932	0.8124	0.8231	0.7747	0.7481
0.7623	0.8518	0.8373	0.7764	0.7652	0.7743	0.7912	0.7331	0.7194	0.7026	0.8465	0.9948	1.0636	1.0778	1.0845	1.1017	1.0574	1.0311
0.6849	0.6726	0.6106	0.6232	0.6085	0.6475	0.6719	0.6443	0.7166	0.7445	0.8763	0.9083	0.7794	0.8327	0.7855	0.8257	0.8181	0.8583
0.7422	0.8943	0.7937	0.7862	0.7739	0.7679	0.8292	0.8337	0.9121	0.9449	1.1092	1.1518	1.2124	1.2041	1.2465	1.3166	1.3329	1.2516
0.4848	0.4265	0.3927	0.4086	0.4203	0.3996	0.4738	0.4711	0.5062	0.5004	0.6224	0.6682	0.6609	0.6272	0.6263	0.6508	0.6624	0.6278
0.5373	0.5346	0.5054	0.4543	0.4554	0.354	0.4049	0.4057	0.5497	0.6124	0.6922	0.8248	0.8663	0.8942	0.9834	1.1313	1.1348	1.1803
0.5766	0.5679	0.5757	0.5702	0.5752	0.5262	0.582	0.6131	0.5322	0.4947	0.7178	0.7736	1.4539	0.9542	1.08	1.6828	1.2198	1.1964
		1.0247	1.0509	1.0189	0.9805	0.9139	0.8828	0.9095	0.7847	0.8913	0.8336	0.8751	0.9094	0.916	0.9285	0.8953	0.8882
0.7696	0.9424	0.8794	0.867	0.8513	0.8499	0.8008	0.7745	0.7132	0.728	0.7621	0.8716	0.9435	0.9087	0.98	0.878	0.7916	0.8438
0.5178	0.4993	0.5601	0.5414	0.5767	0.5774	0.621	0.6025	0.6338	0.6577	0.6923	0.7087	0.7238	0.709	0.7993	0.7389	0.7898	0.7126
0.8294	0.9632	0.9439	0.873	0.8099	0.7059	0.6014	0.6343	0.6148	0.5788	0.6224	0.6814	0.6681	0.6534	0.7607	0.7434	0.7599	0.805
0.5906	0.5006	0.3872	0.4782	0.5756	0.6369	0.7821	0.5075	0.5087	0.3222	0.6551	0.6546	0.9432	0.6699	0.8605	0.9301	0.7589	0.4696
0.6187	0.6047	0.6399	0.6533	0.6745	0.6936	0.6794	0.6818	0.7548	0.6977	0.8052	0.8896	0.9477	0.9213	0.7483	1.1555	1.0692	0.8941
0.6919	0.7624	0.6923	0.7303	0.7122	0.6937	0.6774	0.6597	0.5963	0.4408	0.6754	0.7288	0.7846	0.8112	0.8626	0.9692	0.9827	0.8519
0.6058	0.5642	0.5941	0.5973	0.5782	0.53	0.5372	0.6047	0.5596	0.5293	0.5697	0.6305	0.6087	0.5646	0.719	0.8693	0.7604	0.6193
0.5803	0.5502	0.5399	0.55	0.5742	0.5714	0.583	0.566	0.63	0.5782	0.5128	0.5329	0.5977	0.6437	0.745	0.8287	0.8385	0.7602
0.7117	0.6222	0.6322	0.6918	0.6846	0.5366	0.5451	0.5411	0.6946	0.6073	0.6896	0.6854	0.7224	0.8208	0.8682	0.883	0.8914	0.8889

Table 1: Chinese construction TFP by province from 1995 to 2012

Region	Province
Northern China	Beijing
	Tianjin
	Hebei
	Shanxi
	Inner Mongolia
North East China	Liaoning
	Jilin
	Heilongjiang
Eastern China	Shanghai
	Jiangsu
	Zhejiang
	Anhui
	Fujian
	Jiangxi
	Shandong
Central and Southern China	Henan
	Hubei
	Hunan
	Guangdong
	Guangxi
	Hainan
South West China	Chongqing
	Sichuan
	Guizhou
	Yunnan
	Tibet
North West China	Shaanxi
	Gansu
	Qinghai
	Ningxia
	Xinjiang

To draw comparisons with other studies on Chinese construction productivity, Xue et al. (2008) observed productivity by region from 1997 to 2003, finding an overall increase from 1997 to 2002 and a decline from 2002 to 2003. Their findings identified a considerable productivity peak in 2002, which was however not observed in this research. There was no significant event in either China's economy as a whole or its construction industry specifically in 2002 which could cause this spike in the productivity curves. In fact, the results in this paper show construction TFP to be fairly low from 1997 up until 2004. Economic growth in eastern seaboard regions has fostered a more demanding and regular market in which only the more productive companies can survive and thrive. A further boost has come from the clustering of construction R&D resources (e.g. universities, research institutes, heavy machinery manufacture) in these regions. Wang et al. (2013) reached similar conclusions to this paper, finding regional construction productivity steadily increasing from 2006 to 2010. Through national-level strategies such as the China Western Development strategy, the central government has deliberately encouraged the involvement of eastern Chinese construction companies in construction of southwest with a view to improving construction productivity in these regions. Wang et al. (2013) also report that the central and western region construction sectors are catching up with eastern region productivity through a focus on innovation.

Average construction productivity by province is presented in Figure 2, with regional groupings highlighting low productivity results for the densely urbanised provinces of Beijing, Shanghai and Guangdong. The strong results in Zhejiang, Jiangsu and Hunan provinces are also important observations. These results contradict those released by the NBSC in various years, which report much higher overall labour productivity by gross output value in Beijing, Tianjin, Shanghai, Hubei, and Hainan than in other provinces. However, the NBSC's productivity estimates are derived simply by dividing working hours of employees by real GDP, thereby capturing only part of the production process. The results in this research encompass labour, capital and energy inputs, as well as both output value and output quality components. The contradictory results could therefore be attributable to high amounts of capital or energy inputs relative to output value, or to the small floor space of buildings constructed in the previously mentioned regions.

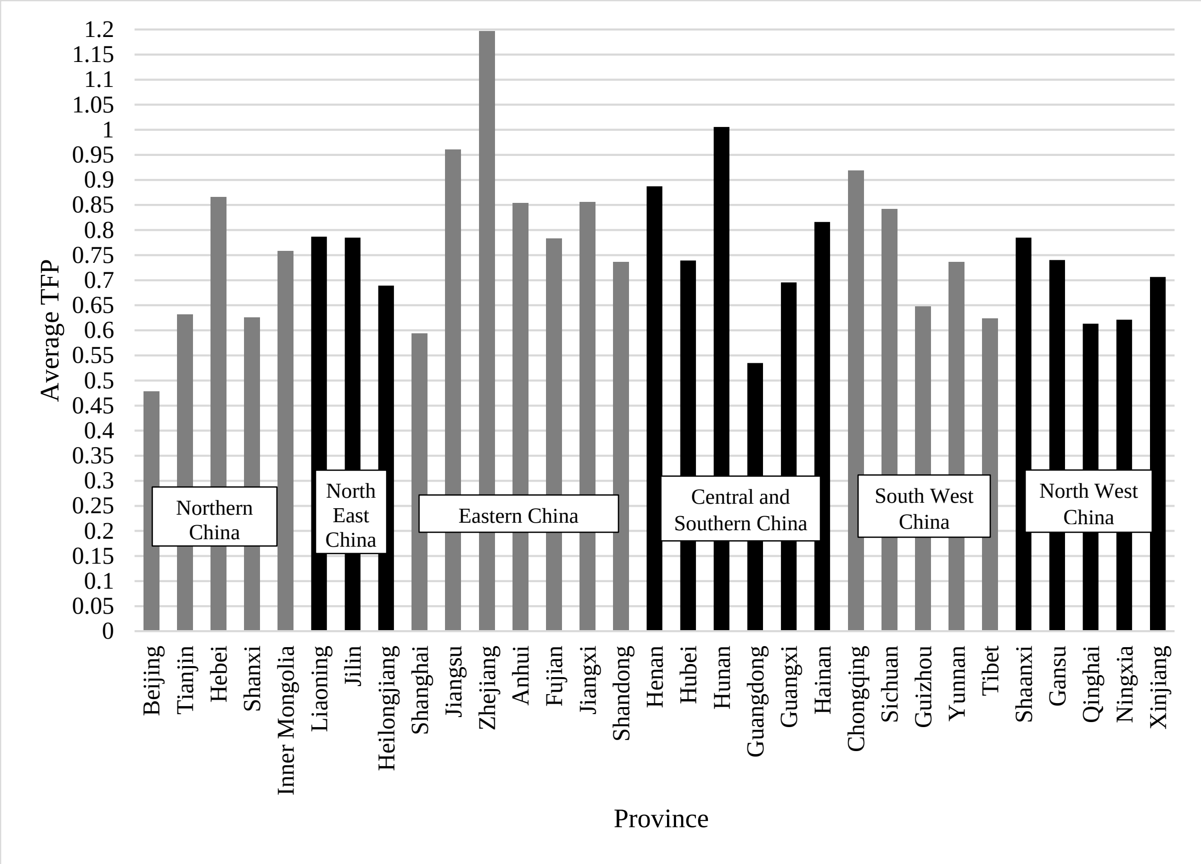

Figure 2: Average construction TFP by province from 1995 to 2012#

Data source: Input and output data from China Statistical Yearbooks 1996 to 2013

 # Chongqing average is from 1997 to 2012

Technical and scale efficiency

As mentioned earlier, technical efficiency is defined as the ability to obtain maximum output from a given set of inputs (Farrell 1957). It therefore captures improvements in processes, in technology and other technical aspects of efficiency. Gains in efficiency are likely to result in productivity improvement, as greater outputs are produced relative to inputs. Input-orientated technical efficiency measures the amount by which inputs can be reduced without resulting in output change. It is a more suitable measure for this study because construction firms tend to have more control over their labour and capital inputs than their output, which is determined externally by clients. Figure 3 presents input technical efficiency by region from 1995 to 2012. A value of 1 in Figure 3 indicates that the observation is on the DEA frontier and demonstrates full technical efficiency for the respective period. The lower the value below 1, the further away it is from the frontier, and thus the more technically inefficient the region is.

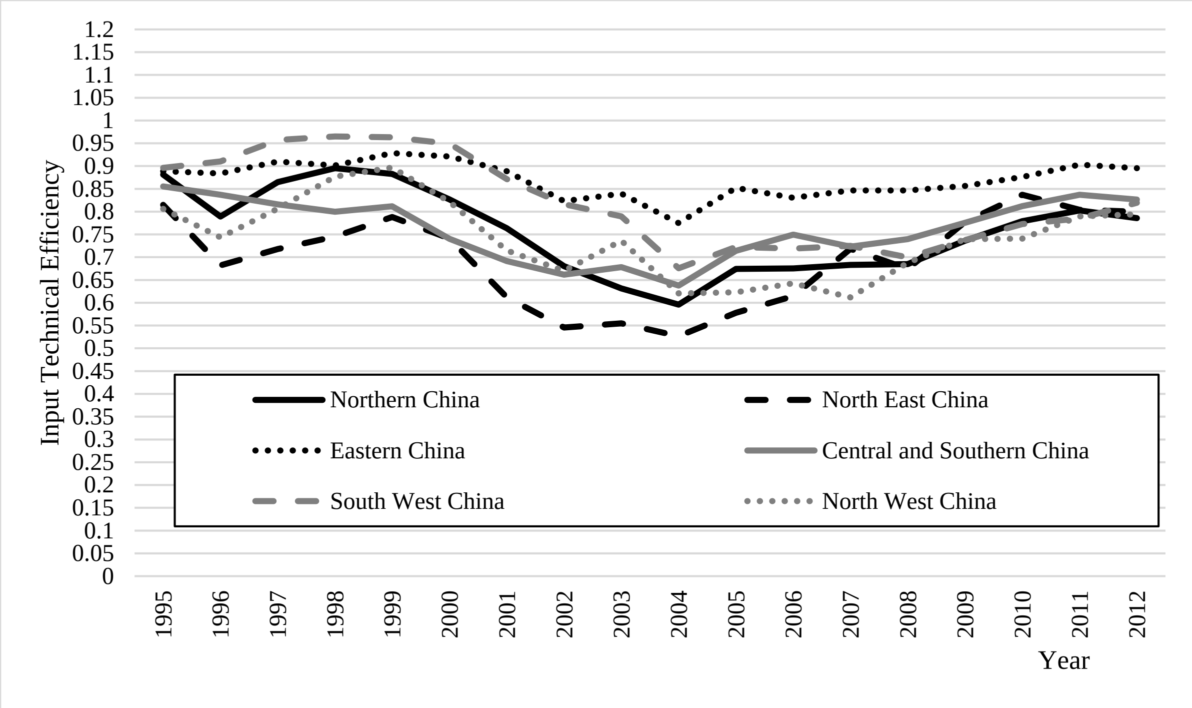

Figure 3: Average input technical efficiency by region from 1995 to 2012

Data source: Input and output data from China Statistical Yearbooks 1996 to 2013

Eastern China was found to have the highest technical efficiency results overall, with a further boost from clustering of construction R&D resources in this region, providing a partial explanation for its higher productivity than its counterparts in other parts of China. As mentioned above, a demanding construction market in Eastern China has forced construction companies in this region to raise their productivity, Nevertheless, if construction productivity is examined horizontally, technical efficiency overall has actually demonstrated minimal improvement over the time period measured. Construction technical efficiency reached a plateau in the late 1990s, declined to its lowest point in 2004, and has slowly been catching up since but yet to be back to previous plateau. The late 1990s plateau can probably be explained by economic acceleration in China at that time, coupled with central government calls for avoidance of *low quality, repetitive construction* and reliance instead on *technical advancement and productivity enhancement* (Lu et al., 2013). Approaching the mid-2000s, several significant factors including the SARS (severe acute respiratory syndrome) outbreak caused economic turbulence and adversely affected construction productivity. Since then, increasing R&D investment has triggered a bounce in construction productivity. According to the NBSC (2010), R&D investment in China was 99.59 billion yuan in 2009, 3.9 times that of the year 2000; however, R&D investment in the construction sector in 2009 was 166.6 million yuan, representing only 0.17 percent of the nation's total R&D investment.

Figure 4 presents regional input-orientated scale efficiency for the Chinese construction industry. As mentioned above, scale efficiency measures whether operations are at an optimal scale to maximize productivity, and input-oriented scale efficiency is observed because construction firms generally have more control over these variables. A value of 1 is an indication of full-scale efficiency; a value of less than 1 indicates the existence of scale inefficiency, and suggests that the scale of inputs should be reviewed. According to Figure 4, China appears to be more scale-efficient than technically efficient, particularly in recent years, with all regions except North West China nearing full-scale efficiency. In addition, Eastern China obtained the highest average scale efficiency results from 1995 to 2012, which is another explanation for this region's high productivity findings.

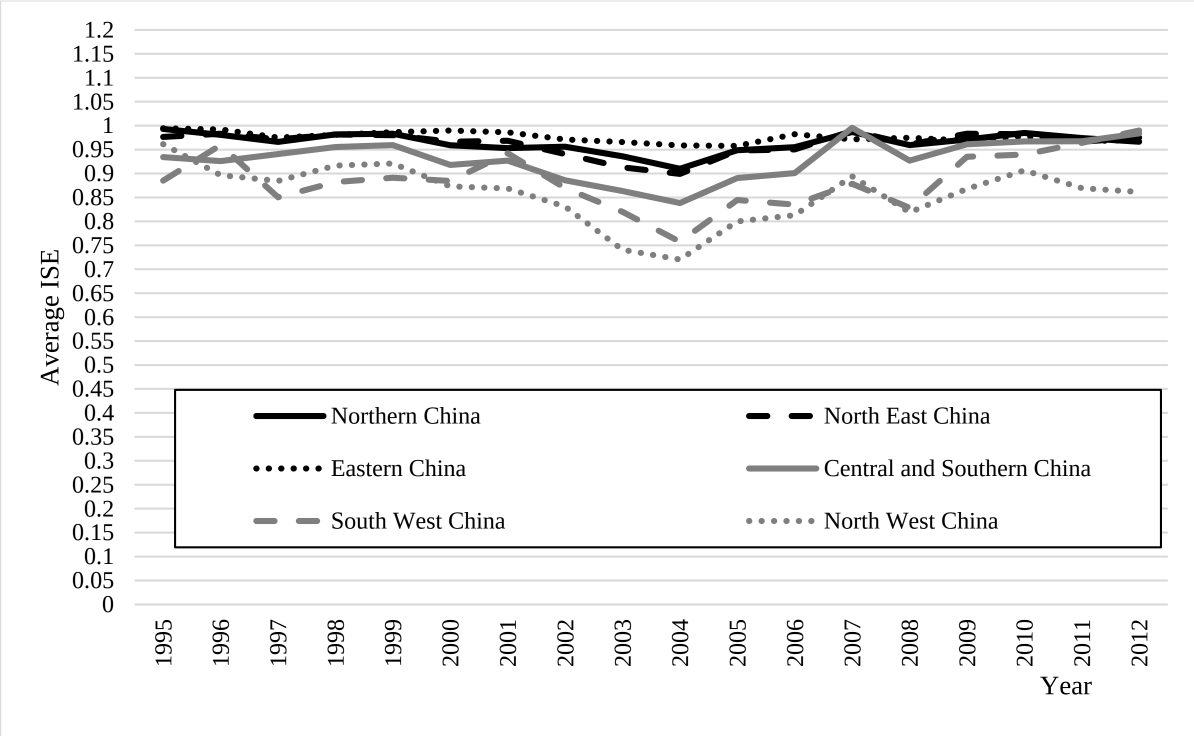

Figure 4: Average input scale efficiency by region from 1995 to 2012#

Data source: Input and output data from China Statistical Yearbooks 1996 to 2013

 # Chongqing average is from 1997 to 2012

Taking the TFP and efficiency findings together, it appears that while the Chinese construction industry has demonstrated reasonably strong scale efficiency, gains in technical efficiency in recent years have been lacking. This reflects the fact that the Chinese construction industry is still, overall, labour-intensive rather than technologically advanced; it also partially explains the post-2009 decrease in productivity growth across all regions. There is an untested hypothesis that scale efficiency may correlate negatively with technical efficiency. A big and lubricate construction market, such as the one in China, may not necessarily guide their companies to enhance construction productivity as a way to survive in the market. Another explanation for the finding in this study of recent productivity decline beyond that indicated by official statistics is the inclusion of the floor-space-constructed output variable. Most Chinese construction productivity studies have relied on a single output approach, often using industry value added only and disregarding changes in construction size and quality. Smaller buildings can generally be constructed with fewer inputs, resulting in a perception of high productivity; including constructed floor space as an output enables an element of quality to be considered in the TFP estimation and decomposition process.

Methodological contributions

Using the Färe-Primont DEA method, this research measured and analysed Chinese construction industry productivity at regional and provincial levels from 1995 to 2012. As in previous studies conducted in this area, disparities across regions and provinces were found. However, some findings are unique. Application of the Färe-Primont DEA method introduced quality of construction as an output variable, leading to a finding of relatively low construction productivity in Beijing, Shanghai and Guangdong. In an applied setting, such an approach is a useful basis for evidence-based strategies or policies aimed at bridging construction productivity gaps, such as the central government's Western Development and Revitalize the Old Northeast Industrial Bases strategies launched in 2000 and 2003 respectively. Construction companies from higher-productivity regions, if appropriately qualified, can freely compete in regions with relatively low productivity and impact their construction efficiency.

The Färe-Primont DEA index can be exhaustively decomposed into input- and output-oriented measures, enabling understanding of construction productivity at a more detailed level. In this research, construction productivity measured with the Färe-Primont DEA index was further decomposed, enabling examination of the technical and scale efficiency of China's construction industry. The finding that it is still labour intensive rather than technology reliant is not new. However, resonating with O'Donnell (2011) the Färe-Primont DEA method, unlike the Malmquist DEA approach, allows for quantitative measurement and close monitoring. Guided by technical and scale efficiency comparisons, conscious measures (e.g. public policies) can be taken to enhance technical efficiency when a construction market can no longer sustain based on its scale to growth.

Conclusions

Using the Färe-Primont DEA method, this research measured construction productivity in various regions and provinces in China with a finding of general growth from a low base in 1995. Unsurprisingly, considerable productivity disparities were discovered. Eastern China led by Zhejiang, Jiangxi, Fujian and Jiangsu was found to have sustained steady and strong productivity growth, while Northern China had the lowest productivity performance. Contradicting received wisdom, the least productive provinces were Beijing, Shanghai and Guangdong. Examining productivity further, it was found that China's construction industry appears to be more scale-efficient than technically efficient. In other words, the industry is operating at near full-scale efficiency to maximise productivity, but relies less on technological advancement. These findings are somewhat contradicting with our accepted orthodox. They shed lights on the productivity in the world's largest construction market. These findings in particular could be used in policy decisions targeting productivity improvement.

The alternative productivity estimation method used in this study helps to explain its contradictory results. The use of appropriate inputs and outputs for TFP estimation overcomes the limitations of single-factor (e.g. labour or capital) productivity estimation. Further, the use of a secondary output factor, in this case constructed floor space, in conjunction with industry value added emphasises the effect on productivity of compensating for construction size and quality, and may explain the lower TFP results in the densely populated provinces of Beijing, Tianjin, and Shanghai. This suggests that developing countries should go beyond consideration of core inputs and outputs in examining construction productivity. The Färe-Primont DEA method also appears to be an effective means of probing construction industry efficiency from different perspectives. It can be exhaustively decomposed into input- and output-oriented estimation of technical-, scale- and mix-efficiency change, allowing for explicit interpretation of factors contributing to productivity.

Future research is recommended to prove the effectiveness of the Färe-Primont DEA method in measuring construction productivity. Productivity is not a tangible subject or entity that can be objectively measured using a standard estimation method. Its measurement depends on selection of input and output and method of calculating the input-output ratio. Therefore, existing methods are normative and their effectiveness needs to be proved. Using the Färe-Primont DEA method, a productivity index can be further decomposed into more detailed levels, such as the technical and scale efficiency of an industry. Future research is thus recommended to examine the dynamics of the two indexes, e.g. how one can impact the other. Based on the research findings, sensible measures can be devised to improve productivity at a specific level, across industries and in an international context.

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