Measuring the Productivity of the Construction Industry in China by Using DEA-Based Malmquist Productivity Indices

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Abstract: Data envelopment analysis (DEA) measures the relative efficiency of decision-making units and avoids any functional specification to express production relationship between inputs and outputs. DEA-based Malmquist productivity index (MPI) measures the productivity change over time. In this paper, the MPI is used to measure the productivity changes of Chinese construction industry from 1997 to 2003. The results of analyses indicate that productivity of the Chinese construction industry experienced a continuous improvement from 1997 to 2003 except for a decline from 2001 to 2002. It is found that there are gaps in productivity development level among western, midland, eastern, and northeastern regions in the Chinese construction industry. The DEA-based MPI approach provides a good tool to support setting up policies and strategic decisions for improving the performance of the Chinese construction industry and promoting the sustainable development of the industry between different regions.

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Introduction

The construction industry is one of the major economic sectors in China. It has been widely recognized that the industry plays a vital role in the process of economic growth (Lu and Fox 2001), as illustrated by the following data. Chinese construction industry achieved 818.1 billion yuan (l US$≈7.64 yuan in June 2007) in total output value in 2003 (an increase of 16.79% from the previous year's 700.5 billion yuan), accounting for 7.02% of the nation's gross domestic product (GDP). Construction enterprises reached 48,688 by the end of 2003, employing 24,142,700 people. Profits totaled 51.99 billion yuan in the year, with taxes at 75.87 billion yuan. (China Statistical Yearbook, 2004).

Statistical data only describe an outline of the Chinese construction industry. In order to mine the data and retrieve information to support macrodecision making of governments and enterprises, which are facing the immense pressure due to market globalization, regulatory changes, and the changing economic climate, especially after China's entry into the World Trade Organization (WTO), it is imperative to adopt effective approaches and tools to dynamically and continuously analyze the efficiency and productivity growth of the industry in depth. The competitiveness of the construction industry can also be enhanced through effective decision making and productivity improvement.

Although productivity is not the only determinant of economic growth, it does provide a measure of economic prosperity and degree of competitiveness of an industry. Productivity analysis can provide valuable information about the effectiveness of economic policies and, thus, provide a useful tool in policy design to improve economic development and industry performance (Lall et al. 2002).

The objectives of the research described in this paper are to measure the Malmquist productivity indices (MPIs) of the Chinese construction industry by using the data envelopment analysis (DEA) approach, and to analyze the productivity changes of the construction industry in China over the period of 1997–2003.

DEA, which was first introduced by Charnes et al. (1978), is a data-oriented method for measuring the relative efficiency of decision-making units (DMUs) performing similar tasks in a production system that consumes multiple inputs to produce multiple outputs. It can be applied to analyze multiple inputs and multiple outputs without preassigned weights; it can be used to measure a relative efficiency based on the observed data without knowing information relating to the production function; and it can incorporate decision maker's preferences into DEA models. Because DEA uses linear programming techniques to determine a best-practice or efficient frontier of DMUs without prior assumptions on the underlying functional forms. it has been applied to various areas of efficiency evaluation (Yun et al. 2004; Chen 2003; Zhu 2002).

A number of research projects have been conducted to explore the use of DEA in the construction industry. Chau et al. (2005) analyzed the relative productive efficiency of construction firms in Hong Kong using the DEA method. They found evidence that supports the catching-up hypothesis. They also found that the

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degree of subcontracting and capital to labor ratio has a negative impact on the relative productive efficiency of construction firms although the latter has positive impact on the growth of technical efficiency over time. McCabe et al. (2005) developed an enhanced contractor prequalification model using DEA together with a methodology for determining a "practical frontier" of best contractors. They argued that the established practical frontier can be used as a regional performance standard for the owner in prequalification and as improvement guidelines for contractors. El-Mashaleh et al. (2007) proposed benchmarking models using DEA. Their models measure construction firm performance on a company-wide basis, foster tradeoff analyses among various performance metrics, and tie the resources expended by construction firms to how well those firms perform overall. The models also provide managers guidance in determining how specific company resources can be reallocated to improve overall company performance. Castro-Lacouture et al. (2007) presented a tool for optimizing purchasing decisions in B2B construction marketplaces based on the theory of DEA, addressing the purchase of construction materials as the last component in the construction supply chain. Cheng et al. (2007) introduced the application of DEA as an alternative credit-scoring model to evaluate borrowers with respect to private finance initiative (PFI) projects. Chiang et al. (2007) introduced the DEA method to input-output $(I-O)$ analyses. They used DEA to calculate the relative efficiency for each industrial sector based on inputs and outputs of an $I-O$ table. A numerical example based on the Japanese case was discussed. They argued that, based upon their research results, strategies and policies could be formulated to overcome difficulties and problems faced by the construction related companies, the construction sector as a whole, and the government as well.

The Malmquist index, which measures productivity change over time, was first introduced by Malmquist (1953) as a quantity index for use in the analysis of consumption of inputs. The MPI was suggested by Caves et al. (1982), who extended the idea of Malmquist. The input-based MPI is defined as the ratio of two input functions by Caves et al. (1982), while assuming no technical inefficiency (Farrel 1957). Färe et al. (1992, 1994a) integrated the method of measuring efficiency from Farrel with the method of measuring productivity from Caves et al. (1982) to develop a DEA-based Malmquist index of productivity change using input and output data. This DEA-based MPI has become a popular tool for measuring productivity change of DMUs over time.

A variety of applications that use the DEA-based MPI to evaluate the productivity change over time have been explored in various industries. Färe et al. (1994a) studied the productivity development in Swedish hospitals operating in a nonmarket environment, where radial DEA efficiency scores are used. Grifell-Tatjé and Lovell (1996) used this method to assess the effect of deregulation on Spanish banks. An empirical investigation of the catch-up hypothesis for a group of high and low countries is conducted by Taskin and Zaim (1997). Mahadevan (2002) used DEA to calculate MPI and divided it into technical change, change in technical efficiency, and change in scale efficiency to explain the productivity growth performance of Malaysia's 28 manufacturing industries from 1981 to 1996. Shestalova (2003) applied both the standard DEA methodology with contemporaneous frontiers and DEA with sequential frontiers to study changes in productivity and efficiency in manufacturing for a sample of 11 organization for economic cooperation and development (OECD) countries over a 20-year period. The factoring of MPIs is used to located sources of productivity growth in his research, i.e., technical progress and catching up. A nonradial MPI where the decision maker's preference over performance improvement can be incorporated is studied by Chen et al. (2003) with an application to measure the productivity change of three Chinese major industries: textiles, chemicals, and metallurgicals during the fourth of 5-year-plan periods. Chen et al. (2003) provided an extension to the DEA-based Malmquist approach by further analyzing the two Malmquist components: technical change and frontier shift. They believe that their new approach not only reveals patterns of productivity change and presents a new presentation along with the managerial implications of each Malmquist component, but also identified the strategy shifts of individual DMUs based on isoquant changes. González and Gasón (2004) estimated MPIs and divided them into tour sources of productivity change to analyze the evolution of the productive patterns in a sample of 80 pharmaceutical laboratories that operated in Spain from 1994 to 2000. Asmild et al. (2004) proposed a combination of approaches, combining DEA window analysis with the Malmquist index approach, to calculate efficiency scores and show the Canadian banking industry's progress over 2 decades (1981–2000). Odeck (2006) used a DEA-based Malmquist index to measure productivity growth in target achievements of the operational units of the Norwegian Public Roads Administration (NPRA) charged with traffic-safety services. His DEA framework applied corresponds to a BCC (Banker et al. 1984) model with unique constant input. Camanho and Dyson (2006) used DEA and Malmquist indices to develop measures for comparing groups of DMUs and illustrated the approach with an application to assess the performance of commercial bank branches in Portugal. The analysis involved the construction of an index reflecting the relative performance of branches in four different regions, which can be decomposed into an index for the comparison of within-group efficiency spread, evaluating internal managerial efficiencies, and an index for the comparison of frontier productivity, reflecting the impact of environmental factors and regional managerial policies on branches' productivity.

In summary MPIs are divided into different components to derive detailed information when applying the DEA-based MPIs to analyze the productivity change in a specific industry. In this paper, the MPI is divided into two components, i.e., the change in technical efficiency and the shift of empirical production frontier, to measure the productivity change of the Chinese construction industry from 1997 to 2003. The next section describes the concepts of MPIs and outlines the theoretical foundation of the DEA method of measuring MPI. Its application to the Chinese construction industry is presented and discussed. The conclusions are drawn in the last section.

DEA-Based Malmquist Productivity Index

Model of DEA-Based Malmquist Productivity Index

Suppose there are n DMUs, each DMU_j $(j=1,2,\ldots,n)$ produces a vector of outputs $y_j^t=(y_{1j}^t \cdots y_{si}^t)$ by using a vector of inputs $x_j^t=(x_{1j}^t \ldots x_{mj}^t)$ at each time period $t, t=1,\ldots,T$. The DEA model at the time period t can be formulated as follows (Charnes et al. 1978):

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$$\theta_0^t(x_0^t,y_0^t)=\min\theta_0$$

$$\text{s.t.}\sum_{j=1}^{n}\lambda_j x_j^t\leqslant\theta_0 x_0^t$$

$$\sum_{j=1}^{n}\lambda_j y_j^t\geqslant y_0^t \qquad (1)$$

$$\lambda_j\geqslant 0, j=1,\ldots,n$$

where $x_0^t=(x_{10}^t,\ldots,x_{m0}^t)$ and $y_0^t=(y_{10}^t,\ldots,y_{s0}^t)$=input and output vectors of DMU_0 among others. Note that model (1) is input-oriented constant return to scale (CRS) DEA model (Chen 2003; Zhu 2002). Returns to scale are technical properties of the production function. If we increase the quantity of all factors employed by the same (proportional) amount, output will increase. These three basic outcomes can be identified, respectively, as increasing returns to scale, constant returns to scale, and decreasing returns to scale. The major property of constant returns to scale production functions is that both the average productivities and the marginal productivities of factors are independent of the scale of production, i.e., they depend on factor proportions only. (More information about the concept of constant "Returns to scale" can be found at ⟨http://cepa.newschool.edu/het/essays/product/returns.htm⟩ (Return to scale 2007).

The efficiency $\theta_0^*(\theta_0^*=\theta_0^t(x_0^t,y_0^t))$ determines the amount by which observed inputs can be proportionally reduced, while still producing the given output level. If $\theta_0^t=1$, then DMU_0 is efficient in time period t. In this condition, DMU_0 is unable to proportionally reduce its inputs and reaches on the empirical production frontier (EPF). If $\theta_0^*<1$, then DMU_0 is inefficient and can reduce its inputs. This shows that DMU_0 is operating below the EPF (Chen 2003).

From t to $t+1$, DMU_0's technical efficiency may change or (and) EPF may shift. MPI can be calculated via the following steps (Färe et al. 1994a; Zhu 2002):

1. Comparing x_0^t to the EPF at time t, i.e., calculating $\theta_0^t(x_0^t,y_0^t)$ in model (1);
2. Comparing x_0^{t+1} to the EPF at time $t+1$, i.e., calculating $\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})$ via the following linear program:

$$\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})=\min\theta_0$$

$$\text{s.t.}\sum_{j=1}^{n}\lambda_j x_j^{t+1}\leqslant\theta_0 x_0^{t+1}$$

$$\sum_{j=1}^{n}\lambda_j y_j^{t+1}\geqslant y_0^{t+1} \qquad (2)$$

$$\lambda_j\geqslant 0, j=1,\ldots,n$$

3. Comparing x_0^t to the EPF at time $t+1$, i.e., calculating $\theta_0^{t+1}(x_0^t,y_0^t)$ via the following linear program:

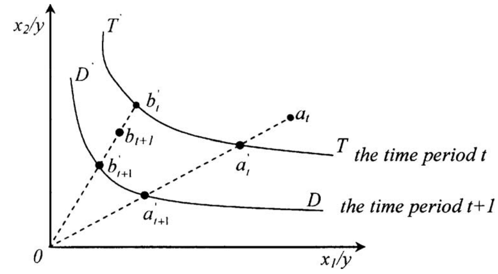

Fig. 1. Efficiency and MPI measures

$$\theta_0^{t+1}(x_0^t,y_0^t)=\min\theta_0$$

$$\text{s.t.}\sum_{j=1}^{n}\lambda_j x_j^{t+1}\leqslant\theta_0 x_0^t$$

$$\sum_{j=1}^{n}\lambda_j y_j^{t+1}\geqslant y_0^t \qquad (3)$$

$$\lambda_j\geqslant 0, j=1,\ldots,n$$

4. Comparing x_0^{t+1} to the EPF at time t, i.e., calculating $\theta_0^t(x_0^{t+1},y_0^{t+1})$ via the following linear program:

$$\theta_0^t(x_0^{t+1},y_0^{t+1})=\min\theta_0$$

$$\text{s.t.}\sum_{j=1}^{n}\lambda_j x_j^t\leqslant\theta_0 x_0^{t+1}$$

$$\sum_{j=1}^{n}\lambda_j y_j^t\geqslant y_0^{t+1} \qquad (4)$$

$$\lambda_j\geqslant 0, j=1,\cdots,n$$

The MPI is defined as

$$MPI_0=\left[\frac{\theta_0^t(x_0^t,y_0^t)}{\theta_0^t(x_0^{t+1},y_0^{t+1})}\frac{\theta_0^{t+1}(x_0^t,y_0^t)}{\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})}\right]^{1/2}$$

The MPI_0 measures the productivity change between periods t and $t+1$. Productivity declines if $MPI_0>1$, remains unchanged if $MPI_0=1$, and improves if $MPI_0<1$.

The MPI_0 can be divided into two components (Färe et al. 1992)

$$MPI_0=\frac{\theta_0^t(x_0^t,y_0^t)}{\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})}\left[\frac{\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})}{\theta_0^t(x_0^{t+1},y_0^{t+1})}\frac{\theta_0^{t+1}(x_0^t,y_0^t)}{\theta_0^t(x_0^t,y_0^t)}\right]^{1/2}$$

where the first component on the right hand side measures the change in technical efficiency (TEC) between periods t and $t+1$, so that

$$TEC_0=\frac{\theta_0^t(x_0^t,y_0^t)}{\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})}$$

The second component, which is the geometric mean, measures the EPF shift (EPFS) between periods t and $t+1$, so that

$$EPFS_0=\left[\frac{\theta_0^{t+1}(x_0^{t+1},y_0^{t+1})}{\theta_0^t(x_0^{t+1},y_0^{t+1})}\frac{\theta_0^{t+1}(x_0^t,y_0^t)}{\theta_0^t(x_0^t,y_0^t)}\right]^{1/2}$$

Then, the MPI_0 can be formulated as follows:

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Table 1. Data Set of Chinese Construction Industry

Region	Year						
	1997	1998	1999	2000	2001	2002	2003
(a) Asset (Unit: 1,000 yuan RMB)							
Western	181,391,910	205,880,020	234,846,900	276,067,660	332,015,940	402,325,750	435,844,750
Eastern	617,893,760	699,043,490	774,354,250	833,368,050	937,582,730	1,111,797,960	1,277,871,640
Midland	156,433,890	174,443,180	193,048,680	204,893,630	247,846,510	320,248,560	369,622,120
Northeast	103,587,990	110,154,470	120,103,010	136,338,180	164,245,160	182,493,820	195,157,270
(b) Employees (Unit: 1,000 persons)							
Western	5,101.1	5,031.4	5,015.0	4,946.1	5,275.2	5,597.2	5,613.4
Eastern	9,800.2	9,455.2	9,457.7	9,488.0	9,894.5	10,575.1	11,639.8
Midland	3,995.5	4,016.9	3,925.3	3,812.6	4,158.0	4,561.0	5,177.4
Northeast	2,118.5	1,796.7	1,803.4	1,696.3	1,779.1	1,718.6	1,712.1
(c) Value added (Unit: 1,000 yuan RMB)							
Western	52,471,790	58,186,550	63,728,000	69,716,700	80,449,460	75,948,500	80,855,340
Eastern	135,856,840	150,349,480	161,491,770	173,176,090	206,472,720	1,961,639,540	237,186,040
Midland	40,915,450	43,793,800	47,078,610	49,790,270	60,675,770	59,577,330	72,294,150
Northeast	24,810,190	24,664,300	27,524,400	31,000,620	36,822,800	29,896,220	32,234,120

$$\mathrm{MPI}_0 = \mathrm{TEC}_0 \cdot \mathrm{EPFS}_0$$

If the value of EPFS_0 is less than 1, it signifies a positive shift or technical progress. If the value of EPFS_0 is greater than 1, it indicates a negative shift or technical regress, and if the value of EPFS_0 is equal to 1, it signifies no shift in EPF (Färe et al. 1992; 1994b). In order to understand the concepts of MPIs, the following subsection briefly presents a visual illustration.

Visual Illustration of DEA-Based Malmquist Productivity Index

Fig. 1 depicts an industry whose production process is measured in two different time periods: the base time period t and a certain time period $t+1$. For visual convenience, all DMUs in the industry use two inputs (x_1 and x_2) to produce a single output (y). The production achievement of DMU_0 at the time period t is depicted on a_t and that of the time period $t+1$ is identified on b_{t+1}.

The EPF, representing the best practice for time period t, is depicted by the smooth curve TT. Note that Models (1)–(4) are constructed based on the assumption of CRS. The EPF forms a cone in the three dimensions (two inputs and one output) (Sueyoshi and Goto 2001). The EPF of time period $t+1$ is depicted by the smooth curve DD'. A radial expansion of b_{t+1} of the time period $t+1$ onto the efficiency frontiers of time period t is visually observed at b_t'. In contrast, a radial expansion of a_t of the time period t onto the efficiency frontier of time period $t+1$ can be visually identified at a_{t+1}' in Fig. 1.

Then the MPI_0 is formulated as follows:

$$\mathrm{MPI}_0 = \left[\frac{oa_t'}{oa_{t+1}'}\frac{ob_t'}{ob_{t+1}'}\right]^{\frac{1}{2}} = \left[\frac{oa_t'}{oa_t}\bigg/\frac{ob_{t+1}'}{ob_{t+1}}\right]\left[\left(\frac{ob_{t+1}'}{ob_{t+1}}\bigg/\frac{oa_t'}{oa_t}\right)\times\left(\frac{ob_t'}{ob_{t+1}}\bigg/\frac{oa_{t+1}'}{oa_t}\right)\right]^{1/2} = \mathrm{TEC}_0 \cdot \mathrm{EPFS}_0$$

where as

$$\mathrm{TEC}_0 = \left[\frac{oa_t'}{oa_t}\bigg/\frac{ob_{t+1}'}{ob_{t+1}}\right]$$

$$\mathrm{EPFS}_0 = \left[\left(\frac{ob_{t+1}'}{ob_{t+1}}\bigg/\frac{oa_t'}{oa_t}\right)\times\left(\frac{ob_t'}{ob_{t+1}}\bigg/\frac{oa_{t+1}'}{oa_t}\right)\right]^{1/2}$$

Measuring Productivity of Construction Industry in China

Data and DMU Selection

The data used in this study came from the *Statistical Yearbook of China* by the Chinese Bureau of Statistics, as published every year during the time period from 1997 to 2003 (see Table 1). The data set includes two inputs: the amount of total assets of the construction industry and the number of total employees

Table 2. DEA Technical Efficiency from 1997 to 2003

Region	$\theta_0^t(x_0^t, y_0^t)$						
	1997	1998	1999	2000	2001	2002	2003
Western	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9598
Midland	0.9523	0.9166	0.9218	0.9623	1.0000	1.0000	1.0000
Eastern	1.0000	1.0000	1.0000	0.9987	1.0000	0.9855	1.0000
Northeast	0.9742	0.9643	1.0000	1.0000	1.0000	0.9378	0.9239
Industry average	0.9816	0.9702	0.9804	0.9902	1.0000	0.9808	0.9709

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Table 3. Value of $\theta_0^{t+1}(x_0^t, y_0^t)$ and $\theta_0^t(x_0^{t+1}, y_0^{t+1})$

	1997–1998		1998–1999		1999–2000		2000–2001		2001–2002		2002–2003	
Region	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Western	1.0235	1.0529	1.0415	1.0297	1.0745	1.0163	1.0315	0.9963	1.2836	0.8025	0.9661	0.9980
Midland	0.9254	0.9640	0.9252	0.9481	0.9657	0.9602	0.9188	1.1418	1.2278	0.8889	0.9464	1.0985
Eastern	0.9579	1.1471	0.9857	1.0738	0.9343	1.0689	0.9926	0.9899	1.2969	0.7869	0.9511	1.0361
Northeast	0.9285	1.0072	0.9421	1.0217	0.9581	1.0816	0.9888	1.1325	1.2446	0.8336	0.8796	1.0149
Industry average	0.9589	1.0428	0.9736	1.0183	0.9832	1.0318	0.9829	1.0651	1.2632	0.8280	0.9358	1.0369

Note: $A=\theta_0^{t+1}(x_0^t, y_0^t)$, $B=\theta_0^t(x_0^{t+1}, y_0^{t+1})$.

in the construction industry, and one output: the amount of value added to the construction industry. Note that the value added to the construction industry refers to the final result of the activities of production and management of construction in monetary terms in the reference period, which is directly presented in the *Statistical yearbook of China*. For additional knowledge, the value of the value added to the construction industry is given by Value added to the construction industry = depreciation of capital assets distilled in the reference year + laborage payable + welfarism payable + insurance and tax of work in overhead expenses + tax and surtax of construction balance + profit of construction balance.

Since a series of economic development plans are designed to boost the developments of different regions, for example, the Western Region Development Program (WRDP) and the revitalization of the old industrial base in Northeast China, all data are grouped into four regions, i.e., western, midland, eastern, and northeast. These four regions represent the different economic development levels. The western region includes 12 provinces in the WRDP: Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, and Inner Mongolia. The midland region consists of Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The eastern region refers to the following ten provinces: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan, which are located on the east coast of China. The northeast region includes Heilongjiang, Jilin, and Liaoning. Each region is considered as a DMU in Models (1)–(4) to measure the productivity change in the Chinese construction industry. The values in monetary terms have been adjusted to a base year 1997 to eliminate the impact of price variations in Table 1.

Computational Results and Discussions

Models (1)–(4) are applied to the data in Table 1 to obtain relative results of efficiency. Table 2 reports the optimal values in Models (1) and (2), i.e., the input-oriented CRS DEA technical efficiency from 1997 to 2003. It can be seen that the western region is the only region that is efficient from 1997 to 2002. This indicates that in the western region it is unnecessary to reduce assets and employees. One of the reasons may be that the Chinese government speeds up the infrastructure construction in the western region during the time periods to implement the WRDP. Regarding the technical efficiency of industry average, it is less than 1 during the time periods, except for the time period of the year 2001. It implies that the performance of the construction industry needs further improvement.

Table 3 reports the optimal values in Models (2) and (3), i.e., the values of $\theta_0^{t+1}(x_0^t, y_0^t)$ and $\theta_0^t(x_0^{t+1}, y_0^{t+1})$.

Applying the data in Tables 2 and 3, the MPIs of the Chinese construction industry can be calculated. Table 4 reports the MPI of the Chinese construction industry in different time periods. Table 5 reports the component shifts in TEC and EPFS during each time period. The changes of MPI, TEC, and EPFS are illustrated in Fig. 2. Note that the industry average of MPI in Table 4 and the industry average of EPFS in Table 5 are equal to the geometrical mean of the samples. The industry average of TEC in Table 5 a the average of the samples. The values of changes in MPI, TEC, and EPFS are calculated by $(1/\text{MPI}_0 - 1)$, $(1/\text{TEC}_0 - 1)$, and $(1/\text{EPFS}_0 - 1)$, respectively.

We first analyze the data of the western region reported in Tables 4 and 5. The values of MPI are greater than 1 in the reported period, except for the time period 1997–1998, which indicates the decline of productivity in the western region from 1998 to 2003. The productivity of the construction industry in western region declines 0.6% from 1998 to 1999, 2.7% from 1999 to 2000, 1.7% from 2000 to 2001, 20.9% from 2001 to 2002, and 0.4% from 2002 to 2003, and only improves 1.4% from 1997 to 1998 (Fig. 2). These results are caused by the negative shifts of EPF, where the values of EPFS_0 are greater than 1 in corresponding time periods, and technical efficiency remains unchanged since the values of TEC_0 are equal to 1 in each time period except the 2002–2003 period. This also means that there is no improvement in technical efficiency in the western region during the period from 1997 to 2002. Note that MPI_0 is the product of TEC_0 and EPFS_0.

Table 4. Malmquist Productivity Index of Chinese Construction Industry

	MPI_0					
Region	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003
Western	0.9860	1.0057	1.0282	1.0176	1.2647	1.0043
Midland	0.9987	0.9850	0.9815	0.9823	1.1753	0.9282
Eastern	0.9139	0.9581	0.9355	0.8964	1.2932	0.9511
Northeast	0.9651	0.9429	0.9412	0.9344	1.2617	0.9379
Industry average	0.9645	0.9727	0.9580	0.9559	1.2472	0.9454

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Table 5. Factoring of Malmquist Productivity Index

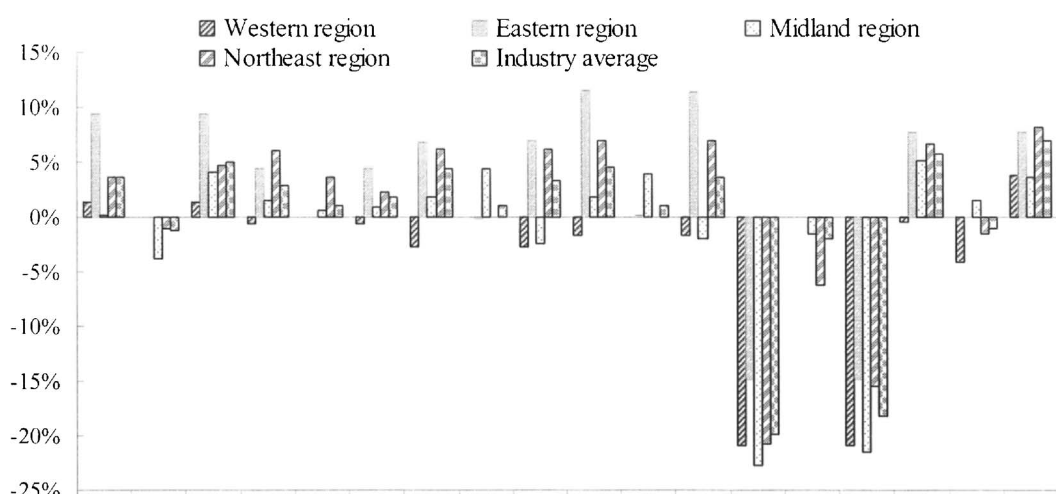
	1997–1998		1998–1999		1999–2000		2000–2001		2001–2002		2002–2003	
Region	TEC_0	$EPFS_0$	TEC_0	$EPFS_0$	TEC_0	$EPFS_0$	TEC_0	$EPFS_0$	TEC_0	$EPFS_0$	TEC_0	$EPFS_0$
Western	1.0000	0.9860	1.0000	1.0057	1.0000	1.0282	1.0000	1.0176	1.0000	1.2647	1.0419	0.9639
Midland	1.0389	0.9613	0.9944	0.9906	0.9579	1.0246	0.9987	0.8976	1.0000	1.1753	1.0000	0.9282
Eastern	1.0000	0.9139	1.0000	0.9581	1.0013	0.9343	0.9623	1.0208	1.0147	1.2744	0.9855	0.9652
Northeast	1.0102	0.9553	0.9643	0.9778	1.0000	0.9412	1.0000	0.9344	1.0663	1.1832	1.0150	0.9240
Industry average	1.0123	0.9528	0.9897	0.9828	0.9898	0.9678	0.9902	0.9654	1.0203	1.2224	1.0106	0.9355

Regarding the midland region, its productivity of the construction industry improved 0.1, 1.5, 1.9, and 1.8% from 1997 to 2001, respectively. The productivity in the midland region declined 22.7% from 2001 to 2002, and improved 5.1% in the 2002–2003 period. The decline results from the negative shift of EPF, because the value of $EPFS_0$ is greater than 1, and the TEC_0 equals 1. Although the shifts of EPF are negative in the time periods 1999–2000 and 2000–2001, the TEC_0 improved 4.4% from 1999 to 2000 and 3.9% from 2000 to 2001. It can also be noted that although the TEC declined 3.7% in the time period 1997–1998, the shift of EPF is positive in 1997–1998, increasing 4%. Overall there is an improvement in productivity from 1997 to 2001.

For the eastern and northeastern regions, the productivity of the construction industry improves during the time period from 1997 to 2003, except for the period 2001–2002. The productivity of the construction industry in the eastern region improves 9.4% in 1997–1998, 4.4% in the time period 1998–1999, 6.9% in 1999–2000, 11.6% in 2000–2001, and 7.7% in 2002–2003, respectively. The improvement of productivity in the time period 2000–2001 is the highest during the time periods and among the four regions, reached 11.6%. The productivity of the construction industry in the northeastern region experienced an improvement of: 3.6, 6.1, 6.3, 7, and 6.6% respectively, in 1997–1998, 1998–1999, 1999–2000, 2000–2001, and 2002–2003. Note that the technical efficiency of the eastern region slightly declined (0.1%) in 1999–2000, but the shift of EPF is positive, which is indicated by the value of $EPFS_0$ (0.9343). The construction industry in the northeastern region also has this phenomenon in the time periods 1997–1998 and 2002–2003.

Looking at the industry average of the Chinese construction industry, it can be seen that the productivity of the industry improved 3.7, 2.8, 4.4, 4.61, and 5.8% in the time periods of 1997–1998, 1998–1999, 1999–2000, 2000–2001, and 2002–2003, respectively, and declined 19.8% in the time period 2001–2002. The decline is caused by the decreasing TEC (0.2%) and EPF (18.2%). It is worthwhile to note that the productivity of the Chinese construction industry starts to decline in 2001–2002, after experiencing continuous improvement from 1997 to 2001.

Comparing the four regions with the industry average (see Table 4 and Fig. 2), it can be found that the improvement of productivity in western and midland regions is less than the improvement of productivity of the industry average, and the improvement of productivity in eastern and northeastern regions is greater than the industry average. Furthermore, the improvement of productivity in the western region is less than the other regions in most time periods. In summary, there are still gaps in the pro-



	MPIo	TECo	EPFSo	MPIo	TECo	EPFSo	MPIo	TECo	EPFSo	MPIo	TECo	EPFSo	MPIo	TECo	EPFSo	MPIo	TECo	EPFSo
		97/98			98/99			99/00			00/01			01/02			02/03	
Western region	0.014	0.000	0.014	-0.006	0.000	-0.006	-0.027	0.000	-0.027	-0.017	0.000	-0.017	-0.209	0.000	-0.209	-0.004	-0.040	0.037
Eastern region	0.094	0.000	0.094	0.044	0.000	0.044	0.069	-0.001	0.070	0.116	0.001	0.114	-0.149	0.000	-0.149	0.077	0.000	0.077
Midland region	0.001	-0.037	0.040	0.015	0.006	0.009	0.019	0.044	-0.024	0.018	0.039	-0.020	-0.227	-0.015	-0.215	0.051	0.015	0.036
Northeast region	0.036	-0.010	0.047	0.061	0.037	0.023	0.063	0.000	0.063	0.070	0.000	0.070	-0.207	-0.062	-0.155	0.066	-0.015	0.082
Industry average	0.037	-0.012	0.050	0.028	0.010	0.017	0.044	0.010	0.033	0.046	0.010	0.036	-0.198	-0.020	-0.182	0.058	-0.010	0.069

Fig. 2. Changes of MPI_0, TEC_0, and $EPES_0$

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ductivity level between different regions in the Chinese construction industry, especially the improvement of productivity in the eastern region, as this is more prominent than the other three regions.

Conclusions

It is widely known that the DEA model can avoid using functional specification to express production relationships between inputs and outputs. The DEA-based MPI approach has been applied to measure the productivity in various industries by many researchers. The input-oriented CRS DEA-based MPIs are used to measure the productivity changes of the Chinese construction industry over the time period from 1997 to 2003. This research divides MPI into two components: TEC and EPFS. TEC measures the magnitude of technical efficiency change between different time periods. EPFS is used to reflect the shift of frontier in different time periods. The MPI is the product of TEC and EPFS. The changes in MPI are determined by both the change of TEC and the change of EPFS in different time periods. This study indicates that productivity of the Chinese construction industry experienced a continuous improvement from 1997 to 2001. It gathers the momentum in 2002–2003 after a decline in 2001–2002. This provides important information for decision makers of government and construction organizations. It is necessary to adopt effective policies and measures to improve the productivity and competitiveness of the Chinese construction industry in the gradually opening construction market. This research also reveals that there still are large gaps of productivity level between different regions in the Chinese construction industry.

This paper introduced the use of DEA-based MPI, which is an input-oriented and radial DEA method, in evaluating the productivity of the Chinese construction industry. Similarly, the output-oriented nonradial DEA-based MPI can be developed when inputs are fixed at their current levels. In the input-oriented DEA model, each DMU can radially reduce its inputs, maintaining the same amount of outputs, until it reaches its efficiency frontier. The output-oriented DEA model offers information on how much each DMU needs to increase its outputs, maintaining the same amount of inputs (Sueyoshi and Goto 2001). The nonradial MPI can also incorporate the preference in performance evaluation. Additionally, although this research employs two inputs and one output factors in the models to calculate MPI of the Chinese construction industry, a multi-input and multioutput DEA-based MPI approach is being expected with valuable potential to find the causes of efficiency or inefficiency of the construction industry. The above mentioned issues will be the directions for future research.

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References

Asmild, M., Paradi, J., Aggarwall, V., and Schaffnit, C. (2004). "Combining DEA window analysis with the Malmquist index approach in a study of the Canadian banking industry." *J. Prod. Anal.*, 21, 67–89.

Banker, R. D., Charnes, A., and Copper, W. W. (1984). "Some models for estimating technical and scale efficiency in data envelopment analysis." *Manage. Sci.*, 30(9), 1078–1092.

Camanho, A. S., and Dyson, R. G. (2006). "Data envelopment analysis and Malmquist indices for measuring group performance." *J. Prod. Anal.*, 26, 35–49.

Castro-Lacouture, D., Medaglia, A. L., and Skibniewski, M. (2007). "Supply chain optimization tool for purchasing decisions in B2B construction marketplaces." *Autom. Constr.*, 16, 569–575.

Caves, D. W., Christensen, L. R., and Diewert, W. E. (1982). "The economic theory of index numbers and the measurement of input, output, and productivity." *Econometrica*, 50(6), 1393–1414.

Charnes, A. A., Cooper, W. W., and Rhodes, E. (1978). "Measuring the efficiency of decision making units." *Eur. J. Oper. Res.*, 2(6), 429–444.

Chau, K. W., Poon, S. W., Wang, Y. S., and Lu, L. L. (2005). "Technological progress and the productive efficiency of construction firms in Hong Kong 1981–2001." *J. Constr. Res.*, 6(2), 195–207.

Chen, Y. (2003). "A nonradial Malmquist productivity index with an illustrative application to Chinese major industries." *Int. J. Prod. Econ.*, 83(1), 27–35.

Chen, Y., and Ali, A. I. (2003). "DEA Malmquist productivity measure: New insights with an application to computer industry." *Eur. J. Oper. Res.*, in press.

Cheng, E. W. L., Chiang, Y. H., and Tang, B. S. (2007). "Alternative approach to credit scoring by DEA: Evaluating borrowers with respect to PFI projects." *Build. Environ.*, 42, 1752–1760.

Chiang, Y. H., Cheng, E. W. L., and Tang, B. S. (2006). "Examining representations of consumptions and inputs placed on the construction sector by use of I-O tables and DEA." *Build. Environ.*, 41, 1–11.

El-Meshaleh, M. S., Minchin, R. E., Jr., and O'Brien, W. J. (2007). "Management of construction firm performance using benchmarking." *J. Manage. Eng.*, 23(1), 10–17.

Färe, R., Grosskopf, S., Lindgren, B., and Roos, P. (1992). "Productivity change in Swedish pharmacies 1980-1989: A nonparametric Malmquist approach." *J. Prod. Anal.*, 3, 85–102.

Färe, R., Grosskopf, S., Lindgren, B., and Roos, P. (1994a). "Productivity developments in Swedish hospitals: A Malmquist output index approach." *Data envelopment analysis: Theory, methodology and applications*, A. Charnes, W. W. Cooper, A. Y. Lewin, and L. M. Seiford, eds., Kluwer Academic, Boston.

Färe, R., Grosskopf, S., Lovell, C. A. K. (1994b). *Production frontiers*, Cambridge University Press, Cambridge, U.K.

Farrell, M. J. (1957). "The measurement of productivity efficiency." *J. R. Stat. Soc. Ser. A (Gen.)*, 120(3), 253–281.

González, E., and Gasón, F. (2004). "Sources of productivity growth in the Spanish pharmaceutical industry (1994–2000)." *Res. Policy*, in press.

Grifell-Tatjé, E., and Lovell, C. A. K. (1996). "Deregulation and productivity decline: The case of Spanish savings banks." *European Economic Review*, 40(6), 1281–1303.

Lall, P., Featherstone, A. M., and Norman, D. W. (2002). "Productivity growth in the western hemisphere (1978-94): The Caribbean in perspective." *J. Prod. Anal.*, 17, 213–231.

Lu, Y. J., and Fox, P. W. (2001). *The construction industry in China: Its image, employment prospects, and skill requirement*, International Labour Office, Geneva, Switzerland.

Mahadevan, S. (2002). "A DEA approach to understanding the productivity growth of Malaysia's manufacturing industries." *Asia Pac. J. Manage.*, 19, 587–600.

Malmquist, S. (1953). "Index numbers and indifference surfaces." *Trabajos de Estatistica*, 4, 209–242.

McCabe, B., Tran, V., and Ramani, J. (2005). "Construction prequalifica-

tion using data envelopment analysis." *Can. J. Civ. Eng.* 32, 183–193.
Odeck, J. (2006). "Identifying traffic safety best practice: An application of DEA and Malmquist indices." *Omega*, 34, 28–40.
"Returns to scale." (2007). ⟨http://cepa.newschool.edu/het/essays/product/returns.htm⟩ (June 6, 2007).
Shestalova, V. (2003). "Sequential Malmquist indices of productivity growth: An application to OECD industries activities." *J. Prod. Anal.*, 19, 211–226.
Sueyoshi, T., and Goto, M. (2001) "Slack-adjusted DEA for time series analysis: Performance measurement of Japanese electric power generation industry in 1984–1993." *Eur. J. Oper. Res.*, 133, 232–259.
Taskin, F., and Zaim, O. (1997). "Catching-up and innovation in high- and low-income countries." *Econ. Lett.*, 54(1), 93–100.
Yun, Y. B., Nakayama, H., and Tannino, T. (2004). "A generalized model for data envelopment analysis." *Eur. J. Oper. Res.*, 157, 87–105.
Zhu, J. (2002). *Quantitative models for performance evaluation and benchmarking: Data envelopment analysis with spreadsheets*, Kluwer Academic, Boston.

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