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Full Length Research Paper

Efficiency and productivity of the Chinese railway system: Application of a multi-stage framework

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This paper models railway operation into three processes: The production process (output/input), the consumption process (consumption/output), and the earnings process (earnings/consumption), making a unified multi-stage framework to measure the performance of Chinese railway bureaus from 1999 to 2008. Firstly, data envelopment analysis (DEA) model is employed to evaluate production efficiency, consumption effectiveness, and earnings effectiveness from the static viewpoint. Secondly, Malmquist TFP index is applied to measure production productivity, consumption productivity, and earnings productivity from the dynamic viewpoint. Thirdly, it assesses the performance of the Chinese railway management system reform in 2005 on railway operations by using an average cumulative Malmquist TFP index.

Key words: Chinese railway system, three-stage railway production analysis, data envelopment analysis, Malmquist TFP index, production efficiency, consumption effectiveness, earnings effectiveness.

INTRODUCTION

Chinese railway has increasingly attracted global attention, because it creates a miracle by running a quarter of the world's railway traffic with only 6% of the world's railway mileage. However, Chinese railway system is still very difficult to satisfy the enormous social demand derived from the rapid economic development. Under the background of globalization, insufficient railway transport capacity is becoming a key obstacle to Chinese economic development. A well-known reason for insufficient railway transport capacity is the low railway density, which needs huge investment to improve. In 2008, the Chinese railway mileage on per square kilometers was 83.1 kilometer, accounting for only 9% of the German railway density. In order to raise railway density, China will invest two trillion RMB on railway system during the period of years 2006 to 2010.

While much attention has been paid to the huge investment on new railway construction, the railway technical inefficiency as another main source of Chinese insufficient railway transport capacity cannot be neglected. Improving railway efficiency is a much more cost-effective method to upgrade railway transport capacity. An objective performance evaluation on Chinese railway system is extremely important, urgent, and necessary. Our study indicates that Chinese railway system is still at a relative low level of technical efficiency mainly affected by the pure technical inefficiency and its production efficiencies is much higher than consumption effectiveness and earnings effectiveness, revealing that the consumption and earnings processes are the weakness in the Chinese railway system. Therefore, it can be shown that the potential efficiency improvement of the existing railway in China is quite huge.

In order to improve railway transport productivity effectively, Chinese railway management mechanism achieved an historical breakthrough in 2005. With the repeal of all railway branches, the four-level management system constituted by Ministry of Railways, railway bureaus, railway branches, and railway sections was abandoned. The problem of two organizations, the railway bureau and railway branch, operating the same assets in the same way was solved through the reform. This four-level system reform made by the Chinese government is an important milestone in Chinese railway development. A quantitative evaluation on the performance of four-level system reform on Chinese

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railway operation will be significant.

Railways play an important role in economic development, attracting more academic evaluations of their performance by using various methods. The first category is the econometrics model based on production economics (Kleins, 1953; Caves et al., 1981), which requires a definite production function form. The second category is the partial-factor productivity index (Nash, 1981; Jackson, 1991) and the total-factor productivity index (Freeman et al., 1985; Hensher et al., 1995; Estache and Gonzalez, 2002), which claims detailed input and output prices. The third category is the stochastic frontier analysis (Gathon and Perelman, 1992; Gathon and Pestieau, 1995), which is very sensitive to the distribution pattern of stochastic variables.

In order to cast off the bondages of specific production function, stochastic variable distribution, and the input/output price index, data envelopment analysis (DEA) is increasingly popular (for example, Chen et al., 2010a, b, c). Oum and Yu (1994) used a DEA model to evaluate the efficiency of railway systems in 19 OECD countries over the period of 1978 to 1989 and two alternative sets of output measures were used: (i) revenue output measures (passenger-kilometers and freight-ton-kilometers); (ii) available output measures (passenger-train-kilometers and freight-train-kilometers). Chapin and Schmidt (1999) measured efficiency for the U.S. since the deregulation by DEA and modeled production in two stages: First, using expenditure on repairs and maintenance as a single input to produce track capacity; second, using train transport capability as one of the main inputs to produce shipments of goods.

Lan and Lin (2005) put forward a four-stage DEA approach to analyze the efficiency of 44 worldwide railway systems over 1995 to 2001 period, and expanded the conventional technical efficiency and productivity measurements to service effectiveness and sales force measurements to reveal the non-storable nature of railway transport. Yu (2008) distinguished the difference between efficiency and effectiveness, and applied the traditional DEA and network DEA models to evaluate the performance of 40 worldwide railway systems. Yu and Lin (2008) proposed that railway transport can be decomposed into production process and consumption process, and established a multi-activity network DEA model to compute passenger technical efficiency, freight technical efficiency, service effectiveness, and technical effectiveness of 20 railway companies in 2002.

From the literature reviews, it can be found that some scholars began to divide railway operation into production process (output/input) and consumption process (consumption/output) based on the non-storable nature of railway service. However, the earnings gained from consumption process are always neglected, which are actually indispensable for the survival of railway firms. Moreover, the previous researches mostly concentrated on the U.S., Canada, Spain, Australia, or OECD countries, and few papers aimed on Chinese railways.

Our research purposes are to have a comprehensive analysis on the efficiency and productivity of Chinese railway system, to distinguish the performance difference among three railway operation processes (including production, consumption and earnings processes), to identify the regional discrepancy among four economic areas (consisting of the Eastern, Central, Western and Northeastern areas), to judge each railway bureau's competitive position, and to evaluate the performance of four-level system reform on Chinese railway operation.

To achieve the purpose, the detailed objectives are discussed further. First, a multi-stage framework of railway performance evaluation is proposed, in which we model railway operations into three processes; not only the production process (output/input) and consumption process (consumption/output), but also the earnings process (earnings/consumption) as an expanded version of the two-stage procedure proposed by Seiford and Zhu (1999) in order to investigate the entire sector. Second, we choose Chinese railway bureaus as decision-making units (DMU), and DEA is applied to evaluate production efficiency, consumption effectiveness, and earnings effectiveness from the static point (Chen et al., 2010 a, b, c; Yang and Chen 2010). Third, Malmquist TFP index is used to measure the changes of production productivity, consumption productivity, and earnings productivity from the dynamic point (Chen and Wang 2010). Fourth, the performance of four-level system reform on Chinese railway operations is assessed by using the average cumulative Malmquist TFP index.

RAILWAY PRODUCTION ANALYSIS

Railway production decomposition

Since the appearance of railways in the early 19th century, railway transport industry has heavily utilized trains to carry passengers and move goods. For ordinary commodities, the measures of technical efficiency (a transformation of outputs from inputs) and technical effectiveness (a transformation of consumption from inputs) are essentially the same, because commodities, once produced, can be stockpiled for consumption. Nothing is lost throughout the transformation from outputs to consumption if one assumes that all the stockpiles are eventually sold (Lan and Lin, 2005). However, when evaluating the performance of railway systems, it is worth noting that, since the transportation services cannot be stored, the output consumption (such as passenger-km) may be substantially different from the output production (such as seat-km) (Yu and Lin, 2008). To elucidate the non-storable characteristics, Fielding et al. (1985) introduced three performance indicators for a transit system: cost efficiency, service effectiveness, and cost effectiveness. Later, the railway transport process began

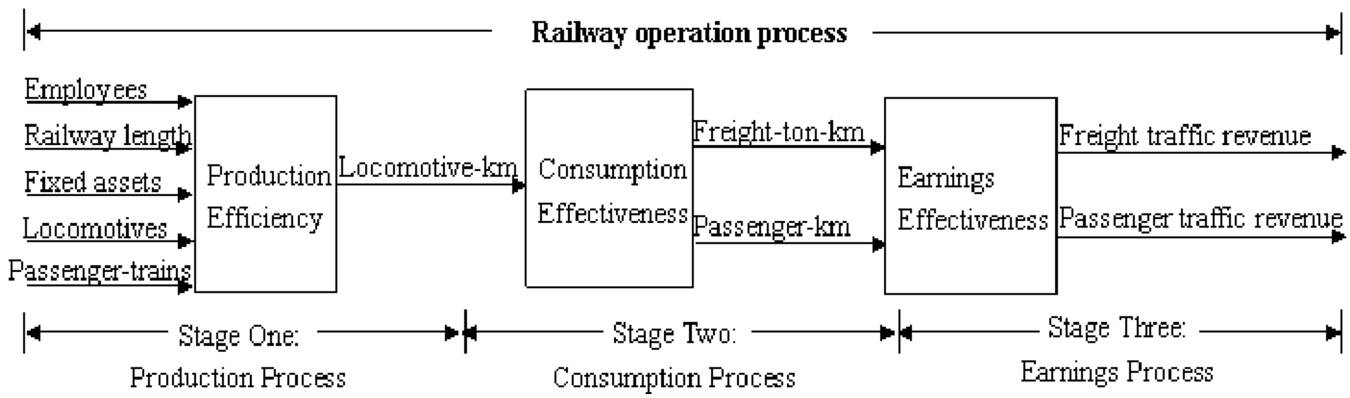

Figure 1. A three-stage railway production analysis.

to be divided into the production process (output/input) and consumption process (consumption/output), which can be seen in Lan and Lin (2005), Yu and Lin (2008), Yu (2008), and Lu et al. (2010).

The end of a railway firm's operation is not the consumption process, because what it really focuses on is the earnings brought about by railway transport consumption. Earnings productivity is also the key indicator for measuring the competitiveness and performance of a railway firm. Since the 1980s, many countries have carried out reforms and reorganizations with state-owned railway, and introduced competition mechanisms into state-owned firms. Many stated-owned railway firms become independent in management and responsible for their own profits or losses. Railway firms offer transport service to meet the social requirement, but they also pay more attention to the earnings brought from the transport process. Gaining reasonable earnings becomes one of the core objectives that railway firms focus on. In view of this, the railway firm operations should not only include the production process (output/input) and consumption process (consumption/output), but also should expand to the earnings process (earnings/consumption). Taking Chinese railways for example, these three processes of railway operations are depicted in Figure 1.

Input-output indicators choice

In the first stage, which is the production process, the initial inputs are used to produce the available outputs, which indicate essentially the level of capacity supplied, and the technical efficiency called production efficiency will be measured. For railway input variables, capital and labor are the most important ones. Based on data availability, this paper chooses the number of employees as labor measurement, and the length of railways in operation, the fixed assets, the number of locomotives, and the number of passenger trains as the capital measurements. Moreover, locomotive-kilometers are used as the single available output. There is no doubt that passenger-train-kilometers and freight-train-kilometers can be output measurements if the data are permitted, but in fact, we can't get the statistical data in China by now. Furthermore, both passenger cars and freight cars should be drawn by locomotives, making locomotive-kilometers a reasonable alternative for passenger-train-kilometers and freight-train-kilometers.

In the second stage, namely the consumption process, the available output will be transformed to actual consumption. Because all of the consumed services are purchased by users or customers (including passengers or shippers), rather than the outputs directly produced by a railway firm, the process of consumption is different from that of production. We define consumption effectiveness to evaluate the technical effectiveness of this stage. In more details, locomotive-kilometers, the output of the production process, will become the intermediate input, and then passenger-kilometers and freight-ton-kilometers are selected as the output measurements.

In the third stage, which is the earnings process, actual revenue will be gained from passenger and freight transports. We define earnings effectiveness to assess the performance of this stage. Passenger-kilometers and freight-ton-kilometers, the output of the consumption process, will become the input indicators. Meanwhile, both passenger traffic revenue and freight traffic revenue are selected as the output indicators.

METHODOLOGY

Production efficiency estimation: Input-oriented DEA

This study employs the DEA model to measure the railway efficiency. The advantages of DEA model are as follows. First, it generally has no strict requirements with the input and output prices, and hence, it can accommodate multiple inputs and outputs.

Second, DEA does not impose any particular functional form on the data, creating a more flexible piecewise linear function (Lin et al., 2010), such that, it can be used to analyze the complex production process. Third, it has the property of unit invariance, making the efficiency measured by DEA model be independent of the units in which the input and output variables are measured. Fourth, the weights of input and output variables are generated by mathematical programming based on the sample data, so, it can avoid the influence of subjective factors. The railway operation can be characterized as a process, converting multiple inputs into multiple outputs, such that the DEA model is suitable for the railway efficiency evaluation.

In the first stage, which is the production process, we use the input-oriented DEA model to measure the maximum possible proportional reduction in all inputs while still keeping all outputs fixed. DEA calculates the relative efficiency of each unit in relation to all other units by using the actual observed values for the inputs and outputs of each DMU (Sufian and Habibullah, 2009). The linear programming problem solved by the input-oriented CCR-DEA model can be expressed as follows:

$$\min_{\theta,\lambda} \theta$$
$$st \quad -y_i + Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0, \; i = 1,2,3...,N$$
$$\lambda \geq 0,$$

where N stands for the number of DMU; each DMU has K inputs and M outputs; the input and output vectors for the i^{th} DMU are x_i and y_i, respectively; X is a K xN input matrix; Y is an M xN output matrix, and λ is a constant vector. The obtained value of θ will be the technical efficiency (TE) score for the i^{th} DMU. The input-oriented BCC-DEA model is added by the convexity constraint: $N1'\lambda = 1$, where $N1$ is an $N \times 1$ vector of ones. The BCC-DEA model permits the calculation of pure technical efficiency (PTE). Moreover, the scale efficiency can be calculated from the difference between pure technical efficiency and technical efficiency: SE = TE/PTE.

In the production efficiency assessment, x_1, x_2, x_3, x_4, and x_5 represent the number of employees, the length of railways in operation, fixed assets, the number of locomotives, and the number of passenger trains, respectively; and y_1 represents locomotive-kilometres. Moreover, TE^P stands for the technical efficiency (also named production efficiency); PTE^P and SE^P represent the pure technical efficiency and scale efficiency of the production process respectively.

Consumption and earnings effectiveness estimations: Output-oriented DEA

In the second and third stages, we measure the consumption effectiveness and earnings effectiveness by using the output-oriented DEA to assess the maximum possible proportional expansion in all outputs while still keeping all inputs fixed.

The linear programming problem solved by the output-oriented CCR-DEA model can be expressed as:

$$\max_{\phi,\lambda} \phi$$
$$\text{s.t.} \quad -\phi y_i + Y\lambda \geq 0$$
$$x_i - X\lambda \geq 0, \; i = 1,2,3...,N$$
$$\lambda \geq 0,$$

where N is the number of DMUs; each DMU has K inputs and M outputs; x_i and y_i represent the input and output vectors for the i^{th} *DMU,* respectively; X is a K xN input matrix; Y is an M xN output matrix; and λ is a constant vector. The obtained value of $1/\phi$ will be the technical efficiency.

When consumption effectiveness is evaluated in the second stage, the details are as follows: x_1 represents locomotive-kilometres; y_1 and y_2 represent freight-ton-kilometres and passenger-kilometres, respectively. Moreover, TE^C stands for the technical effectiveness also named as consumption effectiveness, and PTE^C and SE^C stand for the pure technical effectiveness and scale effectiveness of the consumption process, respectively.

When earnings effectiveness is evaluated in the third stage, the details are as follows: (i) x_1 and x_2 represent freight-ton-kilometres and passenger-kilometres; (ii) y_1 and y_2 represent freight-traffic-revenue and passenger-traffic-revenue. Moreover, TE^E stands for the technical effectiveness also named as earnings effectiveness, while PTE^E and SE^E stand for the pure technical effectiveness and scale effectiveness of the earnings process, respectively.

Productivity measurement of production, consumption and earnings: MPI

Both the CCR-DEA and BBC-DEA models are suited to measure the static efficiency in a certain period, but not able to accommodate the dynamic efficiency change. Hence, Malmquist TFP index is employed to measure the productivity change between different periods (Chen and Wang, 2010). In details, Malmquist TFP index measures the total factor productivity (TFP) change between two data points by calculating the ratio of the distance of each data point relative to a common technology (Coelli et al., 1998).

The output distance function can be defined on the output set, $P(x)$, as:

$$d_o(x,y) = \min\{\delta : (y/\delta \in P(x)\},$$

where $P(x)$ represents the set of output vectors, y, which can be produced by input vector, x. The input distance function can be defined on the input set, $L(y)$, as:

$$d_i(x,y) = \max\{\rho : (x/\rho \in L(y)\},$$

where $L(y)$ represents the set of input vectors, x, which can produce output vector, y.

Following Färe et al. (1994), the output-oriented Malmquist TFP index is specified as:

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} \times \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)}\right]^{\frac{1}{2}} = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{\frac{1}{2}}$$

where the notation $d_o^s(y_t, x_t)$ represents for the output distance from the period *t* observation to the period *s* technology. The notation $m_o(y_s, x_s, y_t, x_t)$ is defined as output-oriented MPI. A value of MPI greater than 1 indicates positive TFP growth from period s to t. The notations $\frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}$ and $\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{\frac{1}{2}}$ measure the technical efficiency change (*EC*) and technical change (*TC*) respectively. Furthermore, the technical efficiency change can be divided into scale efficiency change (*SEC*) and pure technical efficiency change (*PTEC*), that is *EC = SEC x PTEC*.

The definition of output distance function is equal to output-oriented technical efficiency, and the definition of input distance function is equal to the inverse of input-oriented technical efficiency. So the input-oriented Malmquist TFP index can be specified as:

$$m_i(y_s, x_{s,} y_t, x_t) = \left[\frac{d_i^s(y_{s,} x_s)}{d_i^s(y_t, x_t)} \times \frac{d_i^t(y_s, x_s)}{d_i^t(y_t, x_t)}\right]^{\frac{1}{2}} = \frac{d_i^s(y_s, x_s)}{d_i^t(y_t, x_t)}\left[\frac{d_i^t(y_t, x_t)}{d_i^s(y_t, x_t)} \times \frac{d_i^t(y_s, x_s)}{d_i^s(y_s, x_s)}\right]^{\frac{1}{2}}$$

where the notation $d_i^s(y_t, x_t)$ represents for the input distance from the period t observation to the period s technology. The notation $m_i(y_s, x_s, y_t, x_t)$ is defined as input-oriented MPI. A value of MPI greater than 1 indicates positive TFP growth from period *s* to *t*. The notations $\frac{d_i^s(y_s, x_s)}{d_i^t(y_t, x_t)}$ and $\left[\frac{d_i^t(y_t, x_t)}{d_i^s(y_t, x_t)} \times \frac{d_i^t(y_s, x_s)}{d_i^s(y_s, x_s)}\right]^{\frac{1}{2}}$ measure the technical efficiency change (EC) and technical change (TC) respectively.

In order to be consistent with the orientation selection in technical efficiency assessment, we choose input-oriented MPI to measure production productivity change in production process, and output-oriented MPI to measure consumption productivity change in consumption process and earnings productivity change in earnings process. In summary, the research methodology and research framework of this paper are depicted in Table 1.

EMPIRICAL ANALYSIS

Data sources

This paper chooses all the railway bureaus of China as DMUs. Both input and output data are drawn from *China Yearbook of Railway and China Statistical Yearbook of Railroads,* whose publications were started from 1999 and 2006 respectively. Due to the serious data absence in *China Yearbook of Railway* for 1999, the data of 1998 is discarded. Moreover, there are four absent data in 2001, including the numbers of passenger trains and locomotives for both Ji'nan and Chengdu Railway Bureaus. For the data continuity, we infer each of the four data as the average of the values in 2000 and 2002 by assuming the indicators change smoothly. Finally, the panel data of years 1999 to 2008 are selected as the sample.

There were 14 railway bureaus including Harbin, Shenyang, Beijing, Shanghai, Hohhot, Ji'nan, Zhengzhou, Nanchang, Guangzhou, Liuzhou (renamed as Nanning in 2007), Chengdu, Kunming, Lanzhou, and Urumqi Railway Bureaus before 2004. In 2004, Qinghai-Tibet Railway Bureau was founded with Qinghai-Tibet railway opening. In 2005, Beijing Railway Bureau was divided into New Beijing and Taiyuan Railway Bureaus, while Zhengzhou Railway Bureau was divided into New Zhengzhou, Xi'an and Wuhan Railway Bureaus. For the data comparability, Qinghai-Tibet Railway Bureau was discarded and Beijing and Taiyuan Bureaus after 2005 are regarded as a whole to compare with the Beijing Bureau before 2005, while Zhengzhou, Xi'an, and Wuhan Bureaus after 2005 are regarded as a whole to compare with the Zhengzhou Bureau before 2005. Thus, there are 140 observations in all. The descriptive statistics of the original data is portrayed in Table 2.

Production efficiency-consumption effectiveness-earnings effectiveness

The statistical distribution of the production efficiency, consumption effectiveness, and earnings effectiveness of Chinese railways from 1999 to 2008 is depicted in Table 3 and Figure 2.

Comprehensive analysis of Chinese railway efficiency

On average, production efficiency (mean of 0.921) is significantly higher than consumption effectiveness (mean of 0.788) and earnings effectiveness (mean of 0.733) in the Chinese railway system. Moreover, in every year from 1999 to 2008, production efficiency is also always much higher than consumption effectiveness and

Table 1. Method and research framework of this paper.

Stage	Input / Output	Indicators' choice	Efficiency evaluation		Productivity evaluation		
			Efficiency indicators	Model	Productivity indicators	Model	Decomposition of productivity indicators
Production process	Input	Number of employees Length of railway in operation Fixed assets Number of locomotives Number of passenger trains	Production efficiency	Input-oriented DEA Model	Production productivity	Input-oriented MPI	$MPI^P = EC^P \times TC^P$ $EC^P = PTEC^P \times SEC^P$
	Output	Locomotive-kilometers					
Consumption process	Input	Locomotive-kilometers	Consumption effectiveness	Output-oriented DEA Model	Consumption productivity	Output-oriented MPI	$MPI^C = EC^C \times TC^C$ $EC^C = PTEC^C \times SEC^C$
	Output	Freight-ton-kilometers Passenger-kilometers					
Earnings process	Input	Freight-ton-kilometers Passenger-kilometers	Earnings effectiveness	Output-oriented DEA Model	Earnings productivity	Output-oriented MPI	$MPI^E = EC^E \times TC^E$ $EC^E = PTEC^E \times SEC^E$
	Output	Freight traffic revenue Passenger traffic revenue					

earnings effectiveness, which is shown in Figure 2. The Kruskal-Wallis rank test proves that the difference among production efficiency, consumption effectiveness, and earnings effectiveness is statistically significant by a P-value less than 0.001. It can be seen that the weaknesses of Chinese railway system mainly exist in the consumption process and earnings process, which are the key sources of railway inefficiency. These two processes urgently need to be optimized and improved. How the available supply ability can be transformed into efficient consumption and then produce considerable earnings are the significant problems faced by Chinese railways.

As shown in Table 3, both the pure technical efficiency (mean of 0.968) and scale efficiency (mean of 0.952) of the production process are much higher than those of the consumption process (mean of 0.854 for pure technical efficiency and mean of 0.928 for scale efficiency) and earnings process (mean of 0.812 for pure technical efficiency and mean of 0.900 for scale efficiency). The differences are statistically significant by the Kruskal-Wallis rank test with P-values less than 0.001, which are depicted in Table 4. This reveals the main reason for production efficiency to be much higher than consumption effectiveness and earnings effectiveness. In the weaknesses of Chinese railway system including consumption process and earnings process, there are more or less pure technical inefficiency and scale inefficiency, and Nanchang and Zhengzhou, which belong to the Central area; Hohhot, Liuzhou, Chengdu, Kunming, Lanzhou, and Urumqi, which belong to the Western area; and Shenyang and Harbin, which belong to the Northeastern area. Regional efficiency discrepancies are portrayed in Tables 5 and 6.

For the production efficiency, the Eastern, Central, Western, and Northeastern areas are on a close level. The Northeastern area (0.969) is the highest, followed by the Central area (0.968), the Eastern area (0.936), and the Western area (0.878). The slight difference among these areas is statistically insignificant (p=0.058).

For consumption effectiveness, the Eastern area (0.923) ranks first, and then closely followed by the Central area (0.844). The Western area (0.711) and Northeastern area (0.692) significantly

Table 2. Descriptive statistics of the data.

Indicator	Minimum	Maximum	Mean	Standard deviation
Operation line (kilometer)	1623.100	9431.300	4407.382	2280.974
Fixed asset (hundred-million RMB)	66.341	1274.616	374.821	251.279
Employee (thousand)	31.410	245.884	104.678	65.332
Passenger train (One)	831.000	6331.000	2759.707	1461.210
Locomotive (One)	246.000	2987.000	1130.718	687.741
Locomotive-kilometers (million)	23.280	468.150	164.641	106.224
Freight-ton-kilometers (hundred-million)	152.640	4852.780	1242.488	960.112
Passenger-kilometers (hundred-million)	30.070	1432.120	390.869	308.469
Freight traffic revenue (million RMB)	601.820	34424.220	6682.961	6010.294
Passenger traffic revenue (million RMB)	324.380	18393.475	4135.975	3682.012

Table 3. Statistical distribution of static efficiency value in different processes.

Efficiency scores	Production process			Consumption process			Earnings process		
	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
0.000-0.199	0	0	0	0	0	0	0	0	0
0.200-0.299	0	0	0	0	0	0	0	0	0
0.300-0.399	0	0	0	0	0	0	6	2	0
0.400-0.499	2	0	2	1	0	0	20	8	0
0.500-0.599	6	0	6	12	9	0	33	20	3
0.600-0.699	3	1	2	26	21	2	6	20	7
0.700-0.799	7	6	0	30	15	9	12	9	13
0.800-0.899	22	12	3	42	27	21	10	7	33
0.900-0.999	28	19	45	9	16	81	10	10	37
1	72	102	82	20	52	27	43	64	47
Minimum	0.482	0.691	0.482	0.467	0.516	0.619	0.347	0.364	0.554
Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.921	0.968	0.952	0.788	0.854	0.928	0.733	0.812	0.900
Standard deviation	0.127	0.067	0.117	0.137	0.152	0.074	0.230	0.212	0.115

Table 4. Significance test for efficiency difference among different processes.

Indicator	TE	PTE	SE
Chi-square value by Kruskal-Wallis rank test	67.590	49.970	47.693
P-value	<0.001	<0.001	<0.001

Table 5. Regional discrepancy of railway efficiency in China.

Name of region	TE^P	TE^C	TE^E
Eastern area	0.936	0.923	0.787
Central area	0.968	0.844	0.491
Western area	0.878	0.711	0.784
Northeastern area	0.969	0.692	0.716

TE^P stands for production efficiency; TE^C stands for consumption effectiveness; TE^E stands for earnings effectiveness

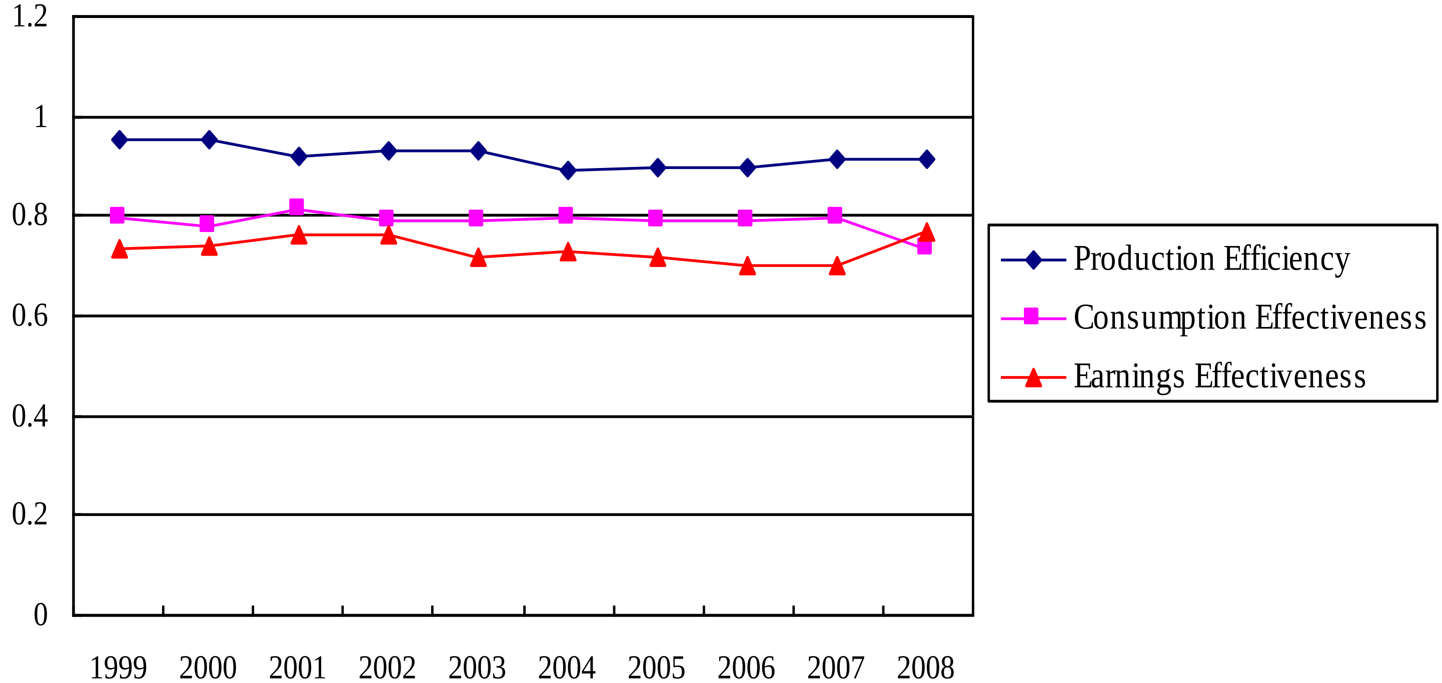

Figure 2. Comparison among different efficiency/effectiveness indicators.

Table 6. Rank tests of regional discrepancy of Chinese railway efficiency.

Indicator	TE^P	TE^C	TE^E
Chi-square value by Kruskal-Wallis rank test	7.481	73.393	25.029
P-value	0.058	<0.001	<0.001

TE^P stands for production efficiency; TE^C stands for consumption effectiveness; TE^E stands for earnings effectiveness.

fall behind. The regional discrepancy of consumption effectiveness is statistically significant (p<0.001).

The regional discrepancy of railway earnings effectiveness is also statistically significant (p<0.001). Though the earnings effectiveness of the Eastern area is only 0.787, it is still the highest among the four areas. The Western area (0.784) ranks second, followed by the Northeastern (0.716) and the Central areas (0.491). This also reflects the general low level of earnings effectiveness in Chinese railways.

We next see the inside of each region. In the Eastern and the Central areas, the production efficiency and consumption effectiveness at around 90%, are relatively higher than the earnings effectiveness which is only 0.787 for the Eastern area and 0.491 for the Central area, which suggests that the earnings process urgently need to be improved in the two areas. In the Western and Northeastern areas, the high production efficiency is a sharp contrast to the low consumption effectiveness and earnings effectiveness, indicating that both the consumption and earnings processes are crucial to improve regional railway systems. Taking the Northeastern area as an example, the production efficiency is 0.969, but its consumption effectiveness and earnings effectiveness are only 0.692 and 0.716, respectively.

Position category of Chinese railway bureaus - based on the efficiency/effectiveness evaluation

The judgment of one railway bureau's competitive position depends on its comparison with the others in Chinese railway system. In order to identify one railway bureau's competitive advantage, we compare its efficiency to the average national level for each of the production, consumption and earnings processes. For example, one bureau's production efficiency higher (lower) than the average national level indicates it has advantage (disadvantage) in production process. Based on each railway bureau's various competitive advantages, the fourteen railway bureaus can be classified into seven categories in 2008, as shown in Table 7. The first category refers to the 'star' DMUs. They have high production efficiency, high consumption effectiveness, and high earnings effectiveness. Accordingly, they have advantages in all of these three processes, for example the Hohhot Railway Bureau.

The second category refers to the 'thin-dog' DMUs, which are the worst ones in Chinese railway system. Liuzhou Railway Bureaus is the single example for the second category. It has poor performances and disadvantages in all of railway operation stages, including production, consumption, and earnings processes.

The other railway bureaus exist in the middle belt between the best and the worst ones. Beijing, Zhengzhou, and Ji'nan Railway Bureaus belong to the third category. Except for the poor earnings effectiveness, they have advantages in both production and consumption processes. As a result, it should focus on earnings process in order to become a 'star' DMU.

The fourth category is consisted of Shanghai, Urumqi, and Harbin Railway Bureaus. They have obvious advantages in both production and earnings processes, but consumption effectiveness is lower than the average national level.

The fifth category includes Nanchang, Lanzhou, and Shenyang Railway Bureaus. They have high production efficiencies, but the performances in consumption and earnings processes are so poor.

Guangzhou Railway Group exists in the sixth category. Except for the advantages in consumption and earnings processes, they have poor performances in production process.

The last category including Chengdu and Kunming Railway Bureaus has advantage in the earnings process. However, the production process and consumption process urgently need improvement.

Dynamic efficiency evaluation: MPI in production-consumption-earnings stages

For Chinese railway system, the average cumulative MPI and its components of the production, consumption, and earnings processes from 1999 to 2008 are depicted in Table 8.

Production productivity, consumption productivity, and earnings productivity

The average annual Malmquist TFP index of the earnings stage is 1.061, indicating its total factor productivity growth at an annual rate of 6.1%, which is higher than those of production (+3.2%) and consumption processes (+1.9%). Moreover, in every year from 1999 to 2008, the MPI of earnings process is always much higher than those of production and consumption processes, except for the periods 1999 to 2000, 2001 to 2002, 2002 to 2003, 2006 to 2007, and 2007 to 2008 in which earnings process ranks the second, as shown in Table 8. The Kruskal-Wallis rank test proves the productivity difference among these three stages shows statistical significance with a P-value of 0.002.

In analyzing the components of the MPI, we find that all three processes made significant technical progresses, and furthermore the earnings process (+0.053) is much higher than the production process (+0.038) and consumption process (+0.029). For technical efficiency, a recession happens in both the production and consumption processes (an average rate of -0.006 for production process, -0.010 for consumption process), while the earnings process show a slight growth at an average rate of 0.007. The statistical test confirms that both of the differences are significant with P-values of 0.028 and less than 0.001 respectively as shown in Table 9.

In summary, both MPI and its components including technical change and technical efficiency change of the earnings process are higher than those of the consumption and earnings processes, as shown in Figure 3. The reasons are as follows: On the one hand, the earnings process has the lowest performance comparing to the other two processes, so there is much more room for further improvement; on the other hand, under rigorous competition, railway bureaus begin to put emphasis on enhancing the earnings process, and hence significant improvement has been gained.

The MPI improvements in the production (+0.032) and consumption processes (+0.019) are mainly rooted in technical progress (0.038 for production process and 0.029 for consumption process), but technical efficiency, falling instead of rising, is caused by the simultaneous decrease of pure technical efficiency and scale efficiency. The MPI improvement (+0.061) in the earnings process is derived from both the technical progress (+0.053) and technical efficiency improvement (+0.007) caused by enhancements in pure technical efficiency (+0.005) and scale efficiency (+0.002) as shown in Figure 3.

Regional discrepancy in Malmquist TFP index

We firstly investigate the regional discrepancy of MPI in different railway operation processes. For the production process, the Central area has the highest MPI (1.045), and then followed by the Eastern (1.033), Western (1.028), and Northeastern areas (1.011). For the consumption process, the Western area has the best performance (1.034), with the Eastern area (1.022) ranked second, and then followed by the Northeastern area (1.014), and a slight recession exists in the Central area (0.996). At the same time, the Central area exhibits

Table 7. Position category of railway bureaus-based on efficiencies/effectiveness evaluation.

Category	Railway bureau	Production efficiency	Consumption effectiveness	Earnings effectiveness	Advantage identification
1	Hohhot	1	1	1	All of three process
2	Liuzhou	0.908	0.685	0.634	None of processes
3	Beijing	1	0.868	0.713	Production process
	Zhengzhou	0.961	0.784	0.508	Consumption process
	Ji'nan	1	0.97	0.555	
4	Shanghai	1	0.715	1	Production process
	Urumqi	1	0.569	1	Earnings process
	Harbin	1	0.524	0.998	
5	Nanchang	0.917	0.607	0.582	Production process
	Lanzhou	1	0.591	0.439	
	Shenyang	0.977	0.728	0.559	
6	Guangzhou	0.683	1	0.939	Consumption process
					Earnings process
7	Chengdu	0.779	0.635	0.795	Earnings process
	Kunming	0.57	0.619	1	
Average national level		0.914	0.735	0.766	------

Table 8. Average cumulative MPI and its components from 1999 to 2008.

Period	Production stage					Consumption stage					Earnings stage				
	MPI	EC	TC	PTEC	SEC	MPI	EC	TC	PTEC	SEC	MPI	EC	TC	PTEC	SEC
1999-2000	1.042	0.995	1.047	0.986	1.010	1.012	0.976	1.037	0.971	1.005	1.025	1.006	1.019	0.999	1.007
2000-2001	1.136	0.961	1.182	0.984	0.977	0.910	1.046	0.87	1.025	1.021	1.168	1.041	1.122	1.005	1.036
2001-2002	1.041	1.010	1.031	1.009	1.001	0.992	0.973	1.02	0.978	0.995	0.997	1.007	0.99	1.005	1.002
2002-2003	1.002	1.001	1.001	1.005	0.996	1.023	0.994	1.03	0.998	0.996	1.018	0.939	1.084	1.014	0.926
2003-2004	1.029	0.955	1.078	0.97	0.984	1.056	1.016	1.04	1.01	1.006	1.105	1.014	1.089	1.019	0.995
2004-2005	1.018	1.007	1.011	1.000	1.007	1.029	0.987	1.042	0.988	0.999	1.074	0.978	1.099	0.982	0.995
2005-2006	1.001	0.994	1.007	0.991	1.003	1.034	1.001	1.033	0.998	1.003	1.061	0.98	1.083	1.002	0.978
2006-2007	1.048	1.028	1.02	1.007	1.021	1.025	1.011	1.014	1.01	1.001	1.036	1.006	1.03	0.995	1.011
2007-2008	0.980	0.997	0.983	1.004	0.993	1.098	0.914	1.201	0.95	0.962	1.071	1.101	0.973	1.025	1.074
Mean	1.032	0.994	1.038	0.995	0.999	1.019	0.990	1.029	0.992	0.998	1.061	1.007	1.053	1.005	1.002

Table 9. Significance test of MPI difference among different processes.

Indicator	MPI	EC	TC	PTEC	SEC
Chi-square value by Kruskal-Wallis rank test	12.459	18.607	7.155	3.024	22.922
P-value	0.002	<0.001	0.028	0.220	<0.001

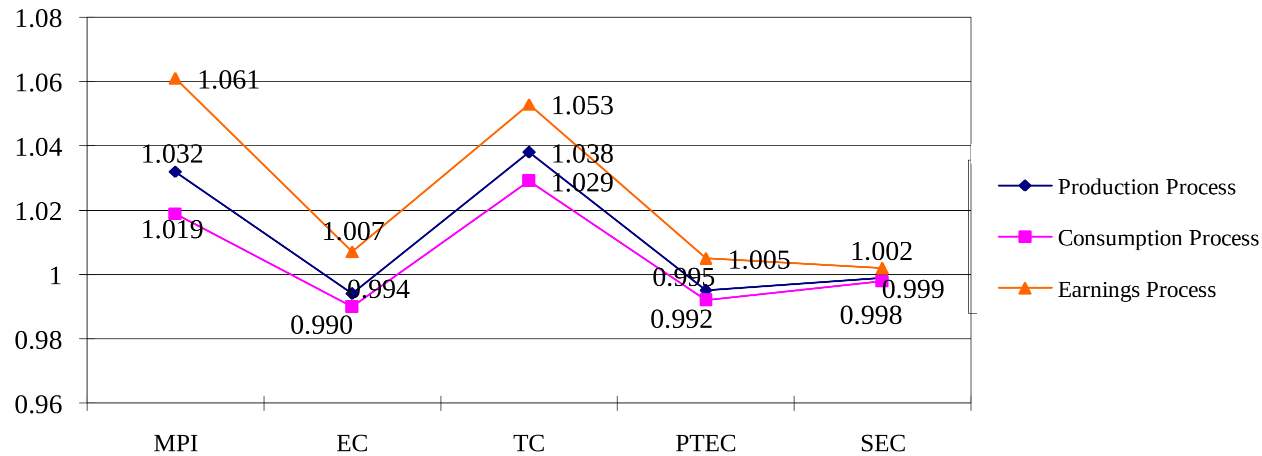

Figure 3. MPI comparison among different processes.

Table 10. MPI of different railway operation processes for different areas.

Name of region	Production process			Consumption process			Earnings process		
	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC
Eastern area	1.033	0.991	1.043	1.022	0.994	1.028	1.058	1.000	1.058
Central area	1.045	0.993	1.052	0.996	0.971	1.025	1.084	1.027	1.056
Western area	1.028	1.025	1.029	1.034	1.027	1.033	1.055	1.036	1.053
Northeastern area	1.011	0.998	1.013	1.014	0.987	1.027	1.059	1.011	1.047

the highest MPI which is 1.084 in the earnings process, and the Northeastern (1.059), Eastern (1.058), and Western (1.055) areas follow closely. The details are depicted in Table 10.

We secondly explore the source of total factor productivity (TFP) change for each railway operation process in every area. In the production process, all four areas achieve favorable TFP improvements. The TFP improvements of the Eastern, Central, and Northeastern areas are mainly derived from technical progress (0.043 for Eastern area, 0.052 for Central area, 0.013 for Western area) while technical efficiency recession exists, but that of the Western area (0.028) benefits from both the technical progress (0.029) and technical efficiency enhancement (0.025).

In the consumption stage, the TFP improvements of the Eastern and Northeastern areas are mainly rooted in technical progress, but that of Western area benefits from both technical progress and technical efficiency improvement. At the same time, the TFP recession happens in Central area mainly affected by the efficiency deterioration.

In the earnings stage, the positive TFP growths exist in all four areas. Furthermore, the TFP improvements of Central, Western, and Northeastern areas are rooted in both technical progresses and technical efficiency enhancement, but that of Eastern area mainly benefits from technical progress while the technical efficiency holding constant as Table 10 shows.

Category of railway bureaus: Based on MPI in different processes

According to the MPI of production, consumption, and earnings processes, Chinese railway bureaus can be classified into two categories, as shown in Table 11. Shanghai, Harbin, Beijing, Huhhot, Zhengzhou, Guangzhou, Liuzhou, Chengdu, Kunming, Lanzhou, Urumqi, Shengyang, and Ji'nan Railway Bureaus belong

Table 11. Average cumulative MPI of each railway bureau from 1999 to 2008.

Name of Railway Bureau	MPI^P	MPI^C	MPI^E	Name of Railway Bureau	MPI^P	MPI^C	MPI^E
Shanghai	1.040	1.007	1.073	Chengdu	1.026	1.006	1.048
Harbin	1.014	1.012	1.055	Kunming	1.027	1.023	1.048
Beijing	1.031	1.03	1.042	Lanzhou	1.046	1.02	1.035
Huhhot	1.031	1.061	1.083	Urumqi	1.040	1.024	1.042
Zhengzhou	1.035	1.008	1.05	Shenyang	1.009	1.017	1.063
Guangzhou	1.008	1.033	1.068	Ji'nan	1.055	1.020	1.049
Liuzhou	1.038	1.02	1.076	Nanchang	1.055	0.985	1.119

MPI^P, MPI^C, and MPI^E stand for the MPI in production stage, consumption stage, and earnings stage respectively.

to the first category. Their MPI of production, consumption, and earnings processes are all larger than 1, which indicates the positive TFP growth happen in all of the railway operation processes. Nanchang Railway Bureaus is the single one in the second category, who only makes TFP improvements in part process of the railway operation. In details, its total factor productivity is significantly upgraded in both the production and earnings processes, but falls in the consumption process.

Evaluating the performance of four-level system reform on railway operation

As previously mentioned, the four-level Chinese railway management system, made of the Ministry of Railways, railway bureaus, railway branches, and railway sections was brought to end in 2005. The reform led to a new three-level management system including Ministry of Railways, railway bureaus, and railway sections, while all the railway branches were removed in order to solve the problems of the railway bureau and railway branch operating the same property in the same way, institutions overlapping, and function repetitiveness. The influence of this reform on railway operations has attracted more and more attention.

In view of this, we use MPI to measure the TFP change before and after the reform, and then adopt the Mann-Whitney rank test to examine the statistical significance of the change. Furthermore, the effect of railway management system reform is estimated. Instead of presenting disaggregated results for each railway bureau and year, we utilize a series of summary descriptions of the average cumulative MPI of all bureaus over the entire period (but divided into pre- and post-reform periods for comparison). Table 12 details the TFP changes before and after the four-level management system reform of Chinese railways.

Production productivity change

Before the railway management system reform, the MPI of the railway production process was 1.049, indicating that production productivity was increasing at an annual growth rate of 4.9%. The production productivity increase was mainly rooted in technical progress (+6.6%), while technical efficiency slightly decreased (-1.6%). For further investigation on the reason why the technical efficiency declined, we find that both technical efficiency recession (-0.9%) and scale efficiency recessions (-0.6%) existed.

After the railway management system reform, the MPI of the production process was 1.012. The test of significance before and after reform yielded a P-value of 0.001, which suggests both the production productivities before and after the reform kept the upward trend, but the growth rate after reform was significant slower.

As for the source of TFP increase, the technical efficiency change score was 1.007 (EC) and the technical change score was 1.005 (TC). This suggests significant technical change and technical efficiency change following the railway system reform, which can be confirmed by the significance test with P-values of 0.003(EC) and 0.000 (TC).

Both the growth in pure technical efficiency (PTEC, +0.1%) and scale efficiency (SEC, +0.6%) resulted in the technical efficiency improvement. The statistical test confirms that the latter was a significant change with a P-value of 0.002, while the former was not with a P-value of 0.114.

Consumption productivity change

The average cumulative Malmquist TFP index of the consumption process presented an annual decline rate of 0.2% during the entire period of 1999 to 2004 for all Chinese railway bureaus as a whole. On average, the decline was mainly attributed to technical recession (-0.3%) while the technical efficiency slightly grew (+0.1%). Moreover, the slight growth in technical efficiency mainly came from scale efficiency improvement (+0.4%), while the recession (-0.4%) happened in pure technical efficiency. The above-mentioned findings denote that in terms of TFP, consumption productivity had been on a downward trend before reform.

After the reform, the downward trend in consumption

Table 12. Changes in various productivities before and after railway reform.

Measures	Mean		Significance test	
	Before reform	After reform	Statistics	Before versus After
First stage: Production productivity				
MPI	1.049	1.012	Z-value P-value	-3.171 0.001
TC	1.066	1.005	Z-value P-value	-4.277 0.000
EC	0.984	1.007	Z-value P-value	-2.895 0.003
PTEC	0.991	1.001	Z-value P-value	-1.850 0.114
SEC	0.994	1.006	Z-value P-value	-2.973 0.002
Second stage: Consumption productivity				
MPI	0.998	1.046	Z-value P-value	-3.978 <0.001
TC	0.997	1.070	Z-value P-value	-4.511 <0.001
EC	1.001	0.978	Z-value P-value	-2.692 0.006
PTEC	0.996	0.986	Z-value P-value	0.306 0.769
SEC	1.004	0.991	Z-value P-value	-2.740 0.005
Third stage: Earnings productivity				
MPI	1.061	1.060	Z-value P-value	-.115 0.910
TC	1.060	1.045	Z-value P-value	-1.795 0.077
EC	1.001	1.015	Z-value P-value	-2.255 0.024
PTEC	1.008	1.001	Z-value P-value	0.742 0.482
SEC	0.993	1.014	Z-value P-value	-3.661 <0.001

productivity was changed thoroughly. The MPI of the consumption process went up to 1.046, showing a growth trend in consumption productivity at annual rate of 4.6%. The test of significance before and after reform yields a P-value less than 0.001, which indicates a statistically significant increase in MPI. This may imply that in terms of TFP, Chinese railways made striking progress in consumption productivity following the railway reform.

As to the components of the MPI, the improvement of consumption productivity was mainly derived from technical progress (TC, +7%), while technical efficiency showed a slight recession (EC, -2.2%). The test of significance yields a P-value less than 0.001 (TC) and a P-value of 0.006(EC) respectively, which confirm both the technical change and technical efficiency change were statistically significant. Further research finds the pure technical efficiency recession (PTEC, -1.4%) and scale efficiency recession (SEC, -0.9%) resulted in technical efficiency decline together, and the statistical test confirms that the latter is significant (p=0.005) , while the former is not (p=0.769).

Earnings productivity change

During the period of 1999 to 2004, the average cumulative MPI of the railway earnings process was 1.061, suggesting earnings productivity was increasing at an annual rate of 6.1% before the railway management system reform. This mainly benefited from substantive technical progress (6.0%), while technical efficiency improvement was very slight (0.1%). Furthermore, the slight technical efficiency improvement was ascribed to the pure technical efficiency growth (0.8%) and scale efficiency recession (-0.7%).

After the reform, the MPI of railway earnings process was 1.060, indicating earnings productivity was increasing at an annual rate of 6.0%. Both the technical change (TC, +4.5%) and technical efficiency change (EC, 1.5%) contributed to the earnings productivity improvement. Decomposing the components of technical efficiency change, it can be seen that pure technical efficiency and scale efficiency were growing at an annual rate of +0.1% (PTEC) and +1.4% (SEC), respectively.

Both technical efficiency change and scale efficiency change are proved to be statistically significant with P-values of 0.024 and less than 0.001. But the MPI, technical change and pure technical change are proved to be statistically insignificant.

To sum up, the results obtained from above-mentioned study have important implications for the railway management system reform. Firstly, all of the three railway operation processes exhibited positive TFP growth after reform, although some of them showed TFP decline before reform. The earnings productivity had the highest increase in TFP after reform, followed by consumption productivity, and production productivity had the relative least growth. Secondly, the MPI of consumption process exhibited statistically significant increases after reform, which indicates that Chinese railways made striking progress in consumption productivity following the railway reform. Meanwhile, the reform slightly slowed down the MPI of production process, and had no obvious effect on earnings productivity. As the significant MPI increase (+0.048) in consumption process was relative higher than the MPI reduction (-0.038) in production process, it can be confirmed that the reform had positive effect on Chinese railway system on the whole. Moreover, the technical progress became the common and main source of the productivity growth in all of these three processes after the reform. The reason may be that the problem, railway bureau and railway branch managing the same property at the same time, was avoided with the repeal of railway branches. This may facilitate better use of existing facilities and also be conducive to the introduction of advanced equipments.

Conclusions

Previous studies on railway efficiency measurement divided the railway operation into output process and service process based on the non-storable nature of railway service, and the earnings process which was very important for the survival of railway firms was always neglected. Hence, this paper models railway operation into production process, consumption process, and earnings process in a multi-stage framework to estimate production efficiency, consumption effectiveness, earnings effectiveness, production productivity, consumption productivity, and earnings productivity simultaneously. Under this framework, we adopt Chinese Railway Bureaus as decision-making units to analyze the performance of Chinese railway system during the period of 1999 to 2008, and furthermore, the performance of the railway management system reform on railway operations is evaluated.

In the first part of empirical analysis, DEA model is used to estimate the production efficiency, consumption effectiveness, and earnings effectiveness of Chinese railway system from the static viewpoint. Our major findings are as follows: First, Chinese railway system is still at a relative low level in technical efficiency, and the consumption effectiveness and earnings effectiveness are much lower than production efficiencies, which suggest the weak links of the Chinese railway system exist in consumption and earnings processes. Second, low pure technical efficiency is the main source for technical inefficiency in all the railway operation processes. Third, for different Chinese regions including Eastern, Central, Western, and Northeastern areas, the production efficiency are on a close level, but the regional discrepancies of consumption effectiveness and earnings effectiveness are statistically significant. Fourth, the position of each Chinese railway bureau is judged. For example, Hohhot Railway Bureau has advantages in all of production, consumption, and earnings processes, making it a ‘star’ railway DMU.

In the second part of empirical analysis, Malmquist TFP index is employed to evaluate the production productivity, consumption productivity, and earnings productivity of Chinese railway system from the dynamic viewpoint. Some findings can be seen from the study. Firstly, the MPI of the earnings stage is much higher than those of the consumption stage and production stage. Secondly, the MPI improvements of the production and consumption processes are mainly rooted in technical progress while technical efficiency recession, and the MPI improvement of the earnings process is derived from both the technical progress and technical efficiency improvement. Thirdly, the regional discrepancy of MPI in Chinese railway system is significant. In more details, the Central area exhibits the highest MPI in production process and earnings process, while the Western area ranks first in the enhancement of consumption productivity. Fourthly, Chinese railway bureaus can be classified into two categories based on the various MPI in different processes.

In the third part of empirical analysis, we apply an average cumulative Malmquist TFP index to appraise the performance of four-level management system reform on Chinese railway operations. On the whole, the reform had positive effect on Chinese railway system. All of the three railway operation processes exhibited positive TFP growth after reform, and the earnings productivity had the highest increase in TFP after reform, followed by consumption productivity, and production productivity had the relative least growth. Especially, the MPI of consumption process transformed from a recession before reform into an increase after reform. Moreover, technical progress became the common and main source of the productivity growth in all of these three processes after the reform.

After the conclusion of our main findings, we now clarify some shortcomings in this paper. For example, in future research, with the improvement of railway statistical data in China, we may substitute locomotive-kilometer with passenger-train-kilometer and freight-train-kilometer, or even use seat-kilometer to substitute for passenger-train-kilometer. We can then measure the available output much more accurately. This goal may be achieved in the future if data limitation can be relaxed.

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