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Research Article

Evaluation of Urban Infrastructure Investment Efficiency: Empirical Evidence from Heilongjiang Province, China

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The rapid growth of urban infrastructure investment in China has brought with it some serious problems that cannot be ignored, such as low investment efficiency and faulty investment decision-making. Therefore, based on the latest research findings related to infrastructure efficiency evaluation theory and evaluation methods, this paper uses empirical evidence from Heilongjiang province to analyze urban infrastructure investment efficiency. To analyze investment efficiency in the province, a new infrastructure investment efficiency evaluation model is developed known as the SDEA-Malmquist model. The model reveals that urban infrastructure investment projects in Heilongjiang province are relatively effective and stable but that the efficiency of such investments varies according to the city in which they are made. Overall efficiency is consistent with the TFC (total final consumption) index, but the index fluctuates within a narrow range between cities due to technological differences.

1. Introduction

As an integral part of a city, urban infrastructure is the measure of a city's healthy and orderly development, and an important indicator of a city's modernization. Along with China's rapid urbanization in recent years, the government has increased its investment in urban infrastructure in order to stimulate the development of the national economy through the associated social, economic, and cultural benefits. In the decision-making process of China's urban infrastructure investment, the decision-making body for urban infrastructure has tended towards diversified patterns in accordance with improved social awareness and a healthy and orderly development of the market economy. The behavior and performance of the decision-making body is an important measure of the effectiveness and scientificity of decisions. Urban infrastructure not only promotes economic development but also causes changes in noneconomic areas such as technical, social environmental, ecological, and political.

The rapid development of urban infrastructure has brought with it wrong investment decisions, which has resulted in a serious waste of resources that not only hinders the development of cities but also causes more serious social problems [1–3]. The configuration of urban infrastructure projects becomes unreasonable and regional development is unbalanced. The investment decision-making body is diversified and the interest relationship becomes complicated. Consequently, scholars have paid particular attention to research in the area of urban infrastructure investment efficiency [4–6].

The purpose of this paper is to scientifically evaluate urban infrastructure investment efficiency in order to avoid the unreasonable allocation of resources and regional imbalance problems. By drawing upon the literature related to infrastructure efficiency evaluation, this paper comprehensively considers and carefully selects the input and output indicators of urban infrastructure investment efficiency and then, based on an analysis of evaluation methods, develops an urban infrastructure investment efficiency model that effectively evaluates the investment efficiency of urban infrastructure both statically and dynamically. Empirical research is used to describe the trends of different cities' investment efficiency and to elaborate on the reasons for different efficiencies in different cities in Heilongjiang province, which can also be applied to the evaluation of cities in other regions of China.

The purpose of the foregoing is to enrich the evaluation methodology of infrastructure investment efficiency and improve the theories of investment efficiency of urban infrastructure, thus providing a basis for the government's macrocontrol of infrastructure investments in China.

2. Literature Review

A variety of research methods and models have been applied to studies of efficiency evaluation. Early studies use efficiency evaluation methods mainly related to econometrics. For example, using the Cobb-Douglas production function to measure the efficiency of an investment involves a variety of cost function methods of statistical analysis [7] and the vector autoregression model of variables, all of which provide a solid foundation for efficiency evaluation. However, only objective time-series data and panel data are applied without taking account of the influence of the relationship between variables on results. Typical of such studies are the following: Aschauer uses America's time-series data and panel data to research the relationship between productivity and capital generated by government expenditure [8]; Munnell uses the production function to measure 40 years of America's basic data and finds out that infrastructure could improve productivity [9]; Lynde and Richmond research the effect of public investment on economic growth with the cost function [10]; Herranz-Loncán uses the vector autoregression model to find that infrastructure could promote the economy and then analyzed the results to discover the reasons for low efficiency [11]. R. F. Wang and J. J. Wang apply the Value-at-Risk (VAR) method to an empirical analysis of Shanghai and conclude that infrastructure and economic growth have mutually reinforcing effects [12].

Along with the multidimensional development of efficiency evaluation metrics, evaluation methods became more complex by combining multiobjective evaluation with efficiency evaluation theory. Although the use of Data Envelopment Analysis (DEA) to research project investment efficiency from all angles and levels has become widely accepted [13–17], the main problem is that it cannot compare effective decision-making units. To overcome this problem, Andersen and Petersen propose an improved DEA model, which they term the "super-efficiency DEA model" [18]. This model considers the efficiency of the evaluated decision-making units with respect to other units, compares the efficiency between effective decision-making units, and sorts effective units. Applications of the super-efficiency DEA model [19–21] and nonparametric methods [22, 23] provide the basis for evaluation of investment efficiency of urban infrastructure.

Although current investment decisions are based on efficiency evaluations that focus on theory evaluation and evaluation methods, there are shortcomings associated with this approach. Firstly, infrastructure investment efficiency should consider noneconomic factors [24], gradually expanding from a single evaluation of economic growth to social assessment, environmental impact assessment, and other aspects; secondly, since most of the empirical research on infrastructure investment efficiency in China covers all the provinces and is therefore general, it cannot be practically applied to guide future investment decisions for specific provinces or regions; finally, in terms of the selection of infrastructure investment efficiency evaluation methods, since the DEA model and nonparametric methods have been applied to energy efficiency evaluation, transportation efficiency evaluation, and real estate project efficiency evaluation, some scholars have suggested that an improved version of the DEA should be applied to efficiency evaluation of infrastructure investment.

To take account of these shortcomings, this paper develops a new model combining Stochastic Data Envelopment Analysis (SDEA) and the Malmquist index to produce the SDEA-Malmquist model that can be used to evaluate urban infrastructure investment efficiency. It is used to empirically analyze the urban infrastructure investment efficiency of China's Heilongjiang province, the results of which can serve as a basis for improving urban infrastructure investment efficiency.

3. Research Design

3.1. Model Selection and Construction. The SDEA-Malmquist infrastructure investment efficiency evaluation model established in this paper consists of two parts. One part is the SDEA model that can calculate the investment efficiency of decision-making units and analyze the relative efficiency of DEA efficient decision-making units; the other is the calculation process of the Malmquist index exponential model, which dynamically analyzes the investment efficiency of urban infrastructure from the perspective of intertemporal evolution.

3.1.1. SDEA Model. In traditional DEA model several DMUs can take score 1; it cannot rank DMUs exactly. The efficiency scores from models are obtained by eliminating the data on the DMU to be evaluated from the solution set [25]. The SDEA model is an improved model based on the DEA model by adjusting its linear programming expression used in calculation. When evaluating the j DMU, it will exclude itself from the constraints. Suppose there are n infrastructure decision-making units and the numbers of inputs and outputs are m and s, respectively. Then the inputted SDEA model and its dual model of the j_0 decision-making unit can be described as follows:

$$\begin{aligned}
\max \quad & \mu^T y_{j_0} + \sigma_1 \mu_0 \\
\text{s.t.} \quad & \omega^T x_j - \sigma_1 \mu_0, \quad j = 1, 2, 3, \ldots, n \ \left(j \neq j_0\right) \\
& \omega^T x_{j_0} = 1 \\
& \omega \geq 0,\ \mu \geq 0,\ \sigma_1 \sigma_2 \left(-1\right)^{\sigma_s} \mu_0 \leq 0 \\
\min \quad & \theta \\
\text{s.t.} \quad & \sum_{j=1, j \neq j_0}^{n} x_j \rho_j + s^- = \theta x_{j_0} \\
& \sum_{j=1, j \neq j_0}^{n} y_j \rho_j - s^+ = y_{j_0}
\end{aligned}$$

$$\sigma_1\left(\sum_{j=1,j\neq j_0}^{n}\rho_j+\sigma_2(-1)^{\partial_s}\rho_{n+1}\right)=\rho_1$$
$$s^-\geq 0,\ s^+\geq 0$$
$$\omega^T x_{j_0}=1,\ j=1,2,3,\ldots,n\ (j\neq j_0) \quad (1)$$

among which X_{ij} represents the investment amount of j decision-making unit to i kinds of inputs and it is more than 0. $\omega=(\omega_1,\omega_2,\ldots,\omega_m)^T$ represents the input variable weights while $\mu=(\mu_1,\mu_2,\ldots,\mu_m)^T$ represents the output variable weights. X_j, Y_j, $j=1,2,3,\ldots,n$, represent the input index value and output index value of the j decision-making unit, respectively. s^+ represents the input redundancy while s^- represents the insufficient amount of output. σ_j represents the adjustment amount of the j decision-making unit.

3.1.2. Malmquist Index Exponential Model. (X_s,Y_s) and (X_t,Y_t) are used to represent the vector production of the period of s and t, respectively. The distance functions of the period of s and t can be expressed by $D_0^s(X_t,Y_t)$ and $D_0^t(X_t,Y_t)$. E_c represents efficiency changes and T_c represents technical changes. Then the Malmquist index of the period of s and t is as follows:

$$M_0^s(X_s,Y_s,X_t,Y_t)=\frac{D_0^s(X_t,Y_t)}{D_0^s(X_s,Y_s)},$$
$$M_0^t(X_s,Y_s,X_t,Y_t)=\frac{D_0^t(X_t,Y_t)}{D_0^t(X_s,Y_s)}. \quad (2)$$

Due to the technical differences in the different periods and the uncertainties of the periods, Färe et al. construct the Malmquist index based on the geometric mean by modeling Fisher's method [26] of constructing ideal index and carried out the decomposition [27], which can be expressed as follows:

$$M_0(X_s,Y_s,X_t,Y_t)=\sqrt{\frac{D_0^t(X_t,Y_t)}{D_0^t(X_s,Y_s)}\times\frac{D_0^s(X_t,Y_t)}{D_0^s(X_s,Y_s)}}=E_c\times T_c \quad (3)$$

among which the efficiency change has the combined effects of the pure technical efficiency change (PECH) and scale efficiency change (SECH); namely,

$$E_c=\text{PECH}\times\text{SECH}. \quad (4)$$

Hence, the decomposition form of the Malmquist index is

$$M_0(X_s,Y_s,X_t,Y_t)=E_c\times T_c=\text{PECH}\times\text{SECH}\times T_c. \quad (5)$$

3.2. Variable Selection and Data Sources

3.2.1. Input Indicators. Input indicators refer to input elements of urban infrastructure that should as accurately as possible reflect the actual situation of urban infrastructure. Using criteria from China's Economic Industrial Classification, this paper divides infrastructure into physical infrastructure and social infrastructure, which is further divided into eight major categories of indicator. However, due to the high popularity of communication transmission service facilities and cultural and sports facilities, and taking into account the difficulty of quantifying indicators and the availability of data, the indicators used in this paper are as shown in Table 1.

3.2.2. Output Indicators. Selection of the output indicators of urban infrastructure investment efficiency has a direct impact on the reliability of the evaluation results, so it is important that they indicate the degree of investment efficiency as accurately as possible. The completed infrastructure will have a significant influence on the economy in the short term, which is mainly reflected by a rapid increase in per capita GDP and per capita disposable income; and in the long term it will have a great impact on social development. As the development of infrastructure has become a major driving force of urbanization, it is therefore an indicator of the influence of urban infrastructure investment on social form. This study therefore chose the level of urbanization, the per capita GDP of urban residents, and the per capita disposable income of urban residents, as the output indicators of urban infrastructure investment efficiency.

3.2.3. Data Sources. To reflect the overall level of urban infrastructure in Heilongjiang province, 12 cities (Harbin, Tsitsihar, Jixi, Hegang, Shuangyashan, Daqing, Yichun, Kiamusze, Qitaihe, Heihe, Mutankiang, and Suihua) in the province are selected as the research sample. The study duration is from 2005 to 2012. The data mainly came from the 2006–2013 Statistical Yearbook of Heilongjiang province. The model is operated by EMS1.3 and DEAP2.1 software.

4. Empirical Research

4.1. Static Efficiency Evaluation of Urban Infrastructure. The data applied to the static evaluation models of investment efficiency of urban infrastructure in the 12 cities of Heilongjiang province are from the year 2005 to 2012. Specific overall efficiency of municipalities, pure technical efficiency, and scale efficiency values are achieved by using output-oriented SDEA.

4.1.1. Analysis of Single Efficiency. Table 2 shows that between 8 and 10 cities have greater comprehensive efficient values than or equal to 1 from 2005 to 2012. The number is relatively stable, indicating that these cities are decision-making units on the frontier of efficient production. Among them, the overall efficiency of Daqing, Harbin, Yichun, Jixi, Hegang, and Shuangyashan is positive from 2005 to 2012, indicating that urban infrastructure investment in those provinces had been at a reasonable level during that time.

Table 1: Input indicators of urban infrastructure investment efficiency.

System level	Indicator	Selection basis of indicator
Transportation facilities	Number of cars owned per ten thousand people	Hardware level of urban public transportation facilities
	Road area per capita	Ability of urban transportation facilities providing services to the urban population
Energy source facilities	Gas penetration	Popularity level of urban energy source facilities
Water conservancy environmental facilities	Water penetration	Actual service scope of urban water supply facilities
Education infrastructure	Number of schools owned per ten thousand people	Capacity of urban education facilities
Social security and welfare facilities	Number of schools and hospitals owned per ten thousand people	Popularity level of urban basic medical facilities
Public management service facilities	Toilet level per ten thousand people	Convenience and development levels of urban living infrastructure
	Public green area per capita	Quality of urban living environment

Table 2: Comprehensive urban infrastructure efficiency of 12 cities in Heilongjiang province.

Value of overall efficiency	2005	2006	2007	2008	2009	2010	2011	2012
≥1	9	9	10	10	9	10	10	8
<1	3	3	2	2	3	2	2	4
Mean	0.976	0.978	0.995	0.993	0.979	0.987	0.978	0.978

The mean value of overall efficiency is in a state of small amplitude fluctuation. The values rise from 2005 to reach a peak of 0.995 in 2007. The reasons for this rise are that the number of DEA efficient values increased to 10 and that the DEA overall efficiency of part of the cities improved. Hence, the mean value of overall efficiency in Heilongjiang province is the highest at values close to 1, meaning that investments can be considered to be effective as a whole. The lowest value of overall efficiency is 0.979 in 2009 from which it began to rise and remained steady at 0.978 in 2010, 2011, and 2012. The level of Heilongjiang's urban infrastructure investment efficiency changes a little on the whole and is very stable. However, as it has not reached the optimal efficiency of resource utilization, there remains room for improvement.

Table 3 shows that the values of pure technical efficiency from 2005 to 2012 are high with very small fluctuations. The lowest mean is 0.996 and the values of pure technical efficiency in 2010 and 2011 both reach 1, showing that all urban infrastructure management mechanisms are relatively advanced and the management level has been high. Only individual cities in 2005 and 2012 need to further improve investment structure and distribution of elements and reasonably adjust the management level in order to achieve optimization.

Although 12 cities in Heilongjiang province did not reach the optimal level of technology other than in 2010 and 2011, the values are very close, indicating that Heilongjiang's overall technical level of urban infrastructure is high. The key to improve investment efficiency is to regulate the size of infrastructure projects.

As shown in Table 4, the value of scale efficiency in 2007 is 0.999, which is very close to the optimal size and only needs to remain unchanged. However, the values of scale efficiency in 2005 and 2011 are low, indicating that Heilongjiang's scale efficiency needs to be improved. The following measures should be taken to address this low efficiency: if it is in the increasing stage of scale the government should increase urban infrastructure and expand the scale; or if it is in the decreasing stage of scale, then other investments and misallocation of resources should be reduced so that infrastructure projects can fully reap the benefits of scale. Except for the value in 2007 being close to the optimal size, values in the other years for the 12 cities in Heilongjiang are all unreasonable, which is why overall efficiency is negative. The reasons for this phenomenon are further analyzed below.

4.1.2. Comparative Analysis of Efficiency. Figure 1 is a comparison chart of Heilongjiang's urban infrastructure investment efficiency from 2005 to 2012. It can be seen that pure technical efficiency is at a high level and is stable in spite of fluctuations. The lowest mean is 0.996 and values of some years even reach 1, indicating that all urban infrastructure management mechanisms are relatively advanced and that the management level has been high. However, the values of scale efficiency from 2006 to 2009 have big fluctuations and the values of overall efficiency are low, indicating unreason able phenomena in scales; the overall efficiency is affected by pure technical efficiency and scale efficiency. Moreover, it is consistent with the trend of scale efficiency, indicating

Table 3: Pure technical efficiency of 12 cities' urban infrastructure in Heilongjiang province.

Value of pure technical efficiency	2005	2006	2007	2008	2009	2010	2011	2012
≧1	10	11	11	11	12	12	12	9
<1	2	1	1	1	0	0	0	3
Mean	0.997	0.996	0.997	0.999	0.996	1	1	0.997

Table 4: Scale of urban infrastructure efficiency for 12 cities in Heilongjiang province.

Value of scale efficiency	2005	2006	2007	2008	2009	2010	2011	2012
≧1	9	9	10	10	9	10	10	8
<1	3	3	2	2	3	2	2	4
Mean	0.979	0.982	0.999	0.994	0.983	0.987	0.978	0.981

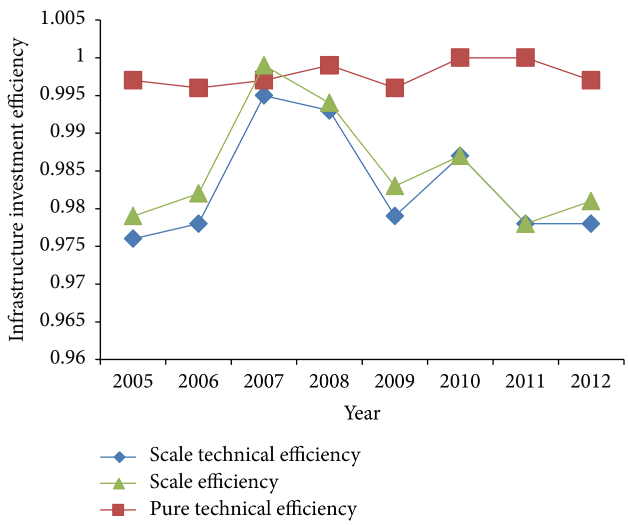

Figure 1: Comparison chart of Heilongjiang's urban infrastructure investment efficiency from 2005 to 2012.

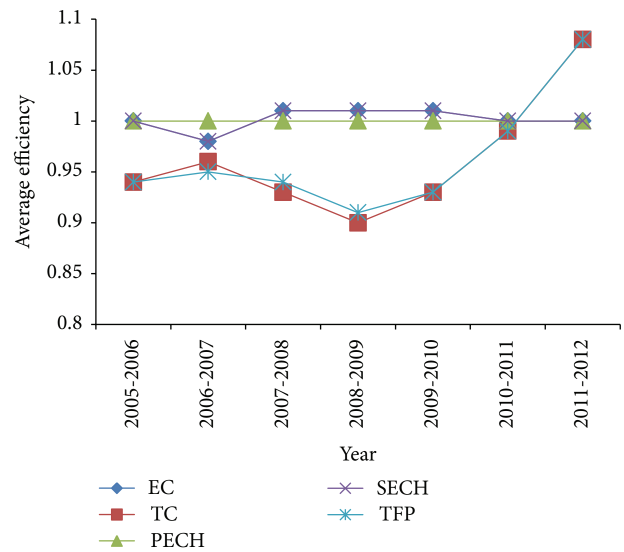

Figure 2: Mean changes in the indicators of Heilongjiang's urban infrastructure investment efficiency from 2005 to 2012.

that Heilongjiang's low investment efficiency is mainly due to scale inefficiency.

4.2. Dynamic Efficiency Evaluation of Urban Infrastructure. From 2005 to 2012, Heilongjiang's infrastructure investment efficiency change index mean is 0.96, which is not much different to the overall efficiency mean of 0.98 in a static analysis. To some extent, this verifies the correctness of the empirical results.

From 2005 to 2007, the index of Heilongjiang urban infrastructure TFP is about 0.94, which is mainly due to the combined effect of the reduction of the efficiency change index and the increase of the technical change index. From 2007 to 2008, the investment efficiency of urban infrastructure decreases year by year and it reaches the lowest value 0.91 from 2008 to 2009. After 2009, it begins to pick up and reaches the highest value 1.08 in 2012, indicating the growing trend of infrastructure investment efficiency. On one hand, it is because the global economic crisis broke out in 2008 spread to China and has a huge impact on China's economy. Then the economy starts to recover along with the government's regulation. Meanwhile, it improves the investment efficiency of urban infrastructure.

4.2.1. Total Factor Productivity (TFP) Index. Figure 2 shows the TFP mean changes in the indicators of Heilongjiang's infrastructure from 2005 to 2012. It can be seen that the value of the TFP index of Heilongjiang's infrastructure from 2005 to 2012 is 0.96, which being less than 1 indicates that infrastructure investment efficiency in Heilongjiang province is in recession during that period.

From 2005 to 2007, the value of the TFP index of Heilongjiang's infrastructure is about 0.94, mainly due to the reduction of the efficiency change index and the increase of the technical change index. From 2007 to 2008 the urban infrastructure investment efficiency decreases reaching the lowest point of 0.91 from 2008 to 2009. After 2009, it begins to pick up and reaches the highest point of 1.08 in 2012, indicating the growing trend of infrastructure investment efficiency. The low point is probably due to the global economic crisis that broke out in 2008 and had a huge negative impact on China's economy. Once the economy started to recover,

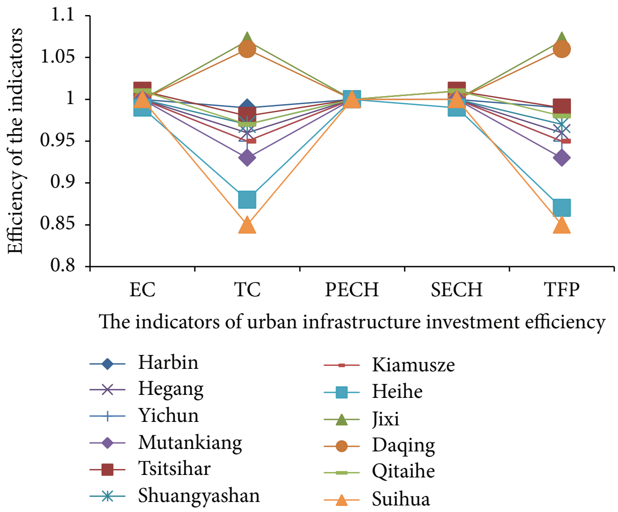

Figure 3: Comparison of the indicators of Heilongjiang's urban infrastructure investment efficiency from 2005 to 2012.

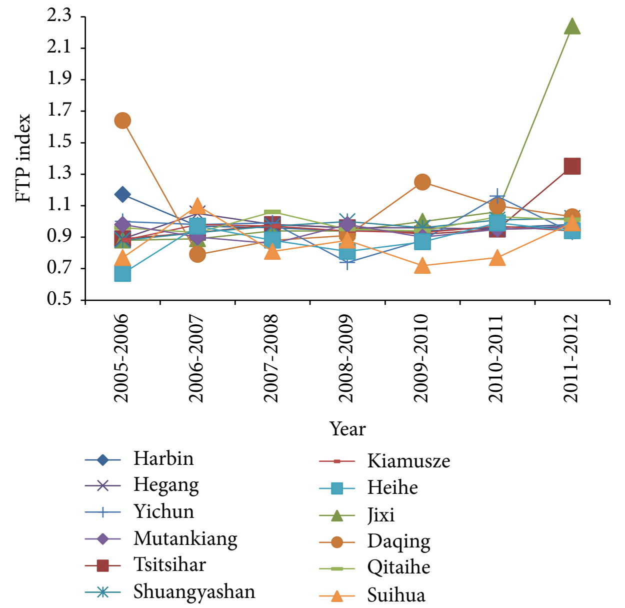

Figure 4: Changes in the TFP index for the urban infrastructure of 12 cities in Heilongjiang from 2005 to 2012.

the investment efficiency of urban infrastructure improves with the help of government regulations.

As shown in Figure 3, the values of the TFP index for Jixi and Daqing are the highest and they are both greater than 1, indicating that urban infrastructure investment efficiency is increasing. This is partly because Jixi and Daqing are resource-oriented cities that are economically strong, which lays a solid foundation for the rational allocation of resources, and partly because of the physical size of the two cities. Harbin, Qiqihar, Shuangyashan, Yichun, Jiamusi, and Qitaihe are in the middle, while Heihe and Suihua are the lowest.

Figure 4 shows the changes in mean values of the TFP index for 12 cities in Heilongjiang from 2005 to 2012 and illustrates the trend of urban infrastructure investment efficiency for those cities. The TFP index changes for Harbin, Qiqihar, Jixi, Hegang, Shuangyashan, Yichun, Jiamusi, and Qitaihe are moderate, fluctuating around 0.9, indicating that the overall urban infrastructure investment efficiency is stable but relatively inefficient because they are less than 1. The TFP index changes for Heihe, Daqing, and Suihua are more pronounced with values larger than 1.5 or smaller than 0.7, indicating greater changes in overall urban infrastructure investment efficiency. The fluctuating level of government's management of infrastructure and the different sizes of infrastructure projects are responsible for these changes.

4.2.2. Evaluation of the Efficiency Change Index. The efficiency change index consists of the pure technical efficiency change (PECH) index and the scale efficiency change (SECH) index. If the value of the PECH index is greater than 1, it indicates that an increase in efficiency is due to an improvement in the level of management; if the value of the SECH index is greater than 1, it means the size of the decision-making unit is close to the optimal size.

Figure 2 shows that the PECH index curve has always been in a horizontal line of 1, indicating that the management level of infrastructure investment has been almost unchanged in eight years. Fluctuations in the efficiency change index are mainly caused by changes of scale. The mean of the efficiency change index is 1.01, indicating that the scale of infrastructure investment in Heilongjiang's 12 major cities is on the rise.

Figure 3 shows that changes in the means of the 12 cities in Heilongjiang for pure technical efficiency from 2005 to 2012 intersect at one point, which is infinitely close to 1. But there are differences in the scale efficiency of different cities, indicating that the mean management level across the various cities over the years has been good. However, the scale efficiency of the different individual cities presents a declining trend.

4.2.3. Evaluation of the Technical Change Index. Technical change means the contribution of border movement of technical production with respect to infrastructure investment efficiency changes from t to $t+1$, which represents the degree of technical progress or innovation. If the technical change index is greater than 1, it indicates that the level of technology has improved; if the technical change index is less than 1, it indicates that the technology is in recession.

Figure 2 shows that the fluctuation of the technical change increased and is largely similar to the trend of the TFP index. The mean of the technological change index is 0.96, indicating that changes in infrastructure investment efficiency are mainly caused by technological changes and that changes in technology do help to improve investment efficiency.

Figure 3 shows that the means of the technological change index for the 12 cities in Heilongjiang have large differences from 2005 to 2012. The values of the technical index changes for Suihua and Heihe are less than 0.9, indicating that the declining trend in these two cities is more obvious and that Jixi and Daqing have made technical progress or have been technologically innovative.

5. Conclusion and Discussion

Effective and rational investment efficiency evaluation systems and evaluation models are important tools for urban infrastructure investment decision-making. Based on existing research results and the traditional DEA model, this paper has made a significant contribution by developing the SDEA-Malmquist model and clarifying its application. The model combines the characteristics of urban infrastructure and factors affecting investment efficiency to establish an efficiency evaluation system. The SDEA part of the model is used to conduct trend analysis of urban infrastructure investment efficiency in 12 major cities in China's Heilongjiang province in terms of overall efficiency, pure technical efficiency, and scale efficiency. The Malmquist index is used to dynamically analyze the intertemporal evolution of urban infrastructure investment efficiency. The main findings and conclusions of this paper are as follows:

(1) Heilongjiang's urban infrastructure investment is effective on the whole, but it shows a declining trend. The mean of Heilongjiang's infrastructure investment overall efficiency is 0.983, which remained stable during the research period. However, from the dynamic analysis of the investment efficiency change index, the mean of 0.96 shows that the investment efficiency is declining.

(2) There are significant differences between different urban infrastructure investments in Heilongjiang. The mean S between Daqing and Mudanjiang is up to 2.16. Pure technical efficiency between different cities is 1 or infinitely close to 1, indicating that the difference of management levels between various cities is not large. The difference of scale efficiency has led to differences in infrastructure investment efficiency. The key issue of intercity difference is whether the size is reasonable, or whether investment is wasted or insufficient.

(3) The overall urban infrastructure investment efficiency of Harbin, Qiqihar, Jixi, Hegang, Shuangyashan, Yichun, Jiamusi, and Qitaih is relatively stable, but the efficiency of investment is declining because it is less than 1. While the FP index changes of Heihe, Daqing, and Suihua are more violent, some values of the TFP index are more than 1.5 or less than 0.7, which also shows great changes in the overall urban infrastructure investment efficiency.

(4) It is recommended that further research should be conducted to analyze the reasons of urban infrastructure inefficiencies; analyze the investment redundancy and output inefficiencies of Qiqihar, Mudanjiang, Jiamusi, and Qitaihe through model results; and clarify the reasons for low investment efficiency so as to provide proper guidance for future infrastructure investment decisions.

Disclaimer

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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