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Measurement of the Operation Efficiency of the Basic Endowment Insurance System for Urban and Rural Residents in China: Based on the Two-Stage Network DEA Model

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Abstract: In the next few decades, China's old-age security system will face the greatest challenge, in order to solve the problem of residents "old age", and in order to reduce the risk of old-age due to population aging, China has successively built urban social old-age insurance and a new rural social old-age insurance system, and in 2014 it was merged into a unified urban and rural residents basic endowment insurance system, which makes China's social security system cover all groups. After more than 8 years of practice, it is of great significance to evaluate the operation efficiency of the basic endowment insurance system for urban and rural residents in China. On this basis, 31 provinces, municipalities and autonomous regions were selected as samples, and the two-stage network data envelopment analysis method was used to calculate the operation efficiency of China's basic endowment insurance system for urban and rural residents from 2014 to 2021, and the DEA-Malmquist index method was used to dynamically analyze the total factor productivity. The results show that: (1) the overall efficiency value of the financing stage and operation stage of the basic endowment insurance system for urban and rural residents in China is basically stable. (2) In the financing stage and operation stage, the average total factor productivity of China's basic endowment insurance system for urban and rural residents from 2014 to 2021 was 1.033, indicating that the increase in total factor productivity was 3.3%, and (3) the technological progress index and pure technological efficiency in various time periods from 2014 to 2021 had a significant impact on the operation efficiency of China's basic endowment insurance system for urban and rural residents.

1. Introduction

As of the end of 2021, the cumulative income of the national basic pension fund for urban and rural residents reached 6,579.3 billion yuan, with expenditures of 6,019.7 billion yuan, resulting in a cumulative surplus of 6,397 billion yuan. In 2021, the population aged 60 and above in China accounted for 18.9% of the total population. According to the standard set by the United Nations, when the proportion of the population aged 60 and above reaches 20%, it indicates that the country or region has entered a moderately aged society. According to this standard, China is approaching a moderate level of aging. With the deepening of population aging in China, the pressure on the urban and rural basic pension insurance system is increasing. In particular, due to significant economic and social disparities among different regions, there are significant variations in the operation of the system between regions. Therefore, this paper theoretically explores the operational efficiency of the urban and rural basic pension insurance system, aiming to ensure its effective and sustainable operation and provide scientific guidance for decision-making in various government departments.

Diamond et al. (1965) conducted in-depth discussions and research on improving the operational efficiency of pension insurance through the pay-as-you-go system and fully funded system [1]. Mercedes (2012) analyzed the operational efficiency of the social pension security system in Spain from the perspective of individual contributions by insured individuals and found a certain inverse relationship between the two [2]. Samuelson (1958) first proposed using the overlapping generations model to evaluate the operational efficiency of pension insurance systems, laying the theoretical foundation for efficiency research in pension insurance [3]. Samuelson (1958) is considered the pioneer of efficiency research in pension insurance systems as he introduced the use of overlapping generations models to study the operational efficiency of pension insurance systems, bringing the study of pension insurance efficiency to a new stage [4]. Wanke and Barros (2016) used a two-stage DEA model to measure the operational efficiency of Brazil's pension insurance system and found that the heterogeneity of insurance companies has a certain impact on their operational efficiency[5]. Li Tao (2018) conducted an empirical study using a three-stage panel DEA model for the urban and rural basic pension insurance systems in 31 provinces (autonomous regions, municipalities) in China from 2012 to 2016. The study analyzed the effects of variables such as GDP growth rate, urbanization level, and elderly dependency ratio on the urban and rural basic pension insurance systems in China [6]. Ma Haichao (2017) empirically studied the operation of pension security systems in different regions of China using the Malmquist model [7]. Through the construction of a non-radial super-efficiency DEA model, Qiang Guomin and Ding Jianding (2020) found that with the development of socio-economics and the acceleration of urbanization, the operational efficiency of China's urban employee pension insurance system will further improve [8]. Wei Yanyan (2019) evaluated the operational efficiency of China's social security system using data from 31 provinces, autonomous regions, and municipalities in China (excluding Hong Kong, Macau, and Taiwan) from 2015 to 2017 through a combination of DEA and Malmquist index methods. The evaluation was conducted from both static and dynamic perspectives [9]. Yu Ning (2017) conducted research from the perspectives of economy, efficiency, and effectiveness, and proposed that improving the replacement rate of pensions and other aspects can enhance the operational efficiency of China's basic pension insurance system [10].

Currently, many scholars at home and abroad have explored the operational efficiency of pension insurance systems, and the use of traditional DEA models for analysis has become relatively mature. However, conducting research on the operational efficiency of the urban employee pension insurance system using the two-stage data envelopment analysis (DEA) method allows for a cross-sectional comparison of the operational efficiency of China's urban and rural basic pension insurance system in the fundraising and operation stages, and identifies the fundamental reasons for low efficiency. Moreover, efficiency calculation involves multiple inputs and outputs, so using the two-stage DEA method to calculate the operational efficiency of China's urban and rural basic pension insurance system is a more effective approach. This paper divides the operation process of China's urban and rural basic pension insurance into the fundraising stage and the operation stage, and constructs a nonlinear super-efficiency two-stage network DEA model. Due to the advantages of super-efficiency DEA, which allows for comparisons between decision-making units when their efficiency values are

1 and the efficiency values of each decision-making unit are not limited to 1, the paper utilizes a two-stage network DEA method with super-efficiency to compensate for the shortcomings of existing DEA methods in optimizing efficiency and conducts empirical research on it.

2. Basic Principles of the Two-Stage DEA Model

As shown in Figure 1, the two-stage structure diagram reveals that each decision-making unit (DMU) is divided into two sub-stages: the fundraising stage (Stage 1) and the operation stage (Stage 2). Let's assume there are n DMUs, and each DMU is denoted as $DMU_j(j=1,2,\cdots,n)$, each DMU_j consists of two stages. In the first stage, the input is represented by $x_{ij}^1(i=1,2,\cdots,m_1)$, and the outputs are denoted by $z_{dj}(d=1,2,\cdots,D)$ and $y_{rj}^1(r=1,\cdots,s_1)$. The output y_{rj}^1 from the first stage does not serve as an input for the second stage, while z_{dj} is considered an intermediate output that serves as an input for the second stage. The exogenous input for the second stage is represented by $x_{ij}^2(i=1,2,\cdots,m_2)$, the desired output is denoted by $y_{rj}^2(r=1,\cdots,s_2)$, and the undesired output is denoted by $y_{rj}^b(r=1,\cdots,s_b)$.

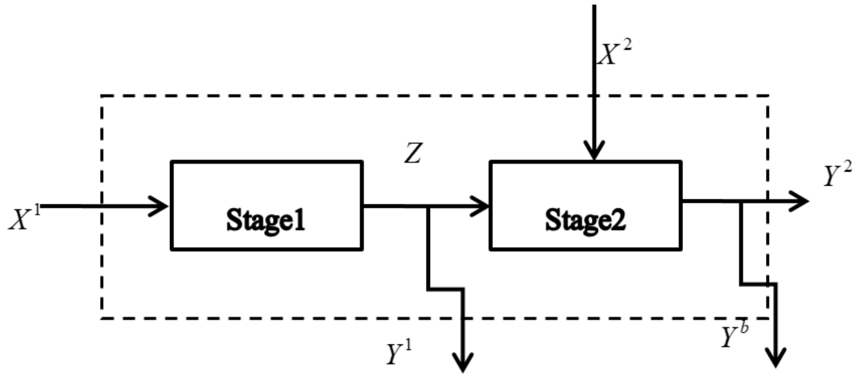

Figure 1: Two-stage Network DEA Structure Diagram

When measuring efficiency, the correlation between these two sub-stages is taken into consideration, and the same weights are assigned to factors of the same type. In this paper, the fundraising stage and the operation stage are regarded as a mutually beneficial relationship. The intermediate variables between the fundraising stage and the operation stage have equal weights, reflecting the reciprocal relationship between the fundraising period and the operation period. In previous studies, there are two methods to calculate overall efficiency: one is in the form of weighted sum, and the other is in the form of multiplication. Therefore, this paper assumes that the intermediate variables have the same weight, denoted as w_d, in both the fundraising stage and the fund operation stage. Both methods are effective ways to aggregate the internal components of the two-step process. The weighted average of the two stages forms the weighted sum two-step model. The determination of weights for each stage requires further consideration of their importance in the overall system. The total efficiency in the form of multiplication is obtained by multiplying the efficiencies of the two sub-stages. In this paper, if the efficiency of either sub-stage is 0, the overall system efficiency is also 0. This means that if the efficiency of the basic pension insurance system for urban and rural residents in China is 0 during the operation stage, regardless of its efficiency in the fundraising stage, the overall efficiency of the entire operation process remains 0. Therefore, this paper sets the model with the following formula:

$$
\begin{aligned}
e_k &= \max e_k^1 * e_k^2 \\
&= \max \frac{\sum_{d=1}^{D} w_d z_{dk} + \sum_{r=1}^{s_1} u_r^1 y_{rk}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ik}^1} * \frac{\sum_{r=1}^{s_2} u_r^2 y_{rk}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rk}^b + u_k^2}{\sum_{i=1}^{m_2} v_i^2 x_{ik}^2 + \sum_{d=1}^{D} w_d z_{dk}} \\
& s.t. \frac{\sum_{d=1}^{D} w_d z_{dj} + \sum_{r=1}^{s_1} u_r^1 y_{rj}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ij}^1} \le 1, \forall j, \\
& \frac{\sum_{r=1}^{s_2} u_r^2 y_{rj}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rj}^b + u_k^2}{\sum_{i=1}^{m_2} v_i^2 x_{ij}^2 + \sum_{d=1}^{D} w_d z_{dj}} \le 1, \forall j, \\
& u_r^1, u_r^2, u_r^b, v_i^2, w_d \ge 0, \forall i, r, d, \\
& u_k^1, u_k^2 free.
\end{aligned} \tag{1}
$$

Through the objective function of model (1), the operational efficiency of the basic pension insurance system for urban and rural residents in China is represented. It can be interpreted as the product of the efficiency of the fundraising subsystem and the investment subsystem. The first two constraints ensure that the efficiency values of each subsystem range from 0 to 1. In the model, $\overline{y}_{rj}^b$ represents the unexpected output of the investment stage, and in this paper, it is transformed as follows: $\overline{y}_{rj}^b = -y_{rj}^b + \omega_r^b (r = 1,2, \cdots, B)$, where $\omega_r^b = \max_j \{y_{rj}^b\} + 1, r \in B$. Model (1) is a fractional programming problem and involves the multiplication of free variables, making it difficult to convert this nonlinear model into a linear one. To address this issue, we employ a heuristic search method and consider the following model as a preliminary step.

$$
\begin{aligned}
e_{k\max}^1 &= \max \frac{\sum_{d=1}^{D} w_d z_{dk} + \sum_{r=1}^{s_1} u_r^1 y_{rk}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ik}^1} \\
& s.t. \frac{\sum_{d=1}^{D} w_d z_{dj} + \sum_{r=1}^{s_1} u_r^1 y_{rj}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ij}^1} \le 1, \forall j, \\
& \frac{\sum_{r=1}^{s_2} u_r^2 y_{rj}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rj}^b + u_k^2}{\sum_{i=1}^{m_2} v_i^2 x_{ij}^2 + \sum_{d=1}^{D} w_d z_{dj}} \le 1, \forall j, \\
& u_r^1, u_r^2, u_r^b, v_i^1, v_i^2, w_d \ge 0, \forall i, r, d, \\
& u_k^1, u_k^2 free.
\end{aligned} \tag{2}
$$

Let the optimal objective function value of model (2) be denoted as $e_{k\max}^1$. Then, the maximum efficiency value of the fundraising subsystem may be $e_{k\max}^1$. Therefore, for the first subsystem e_k^1, its value can be determined, and its range is $[0, e_{k\max}^1]$. Due to the complexity of model (2) and its fractional nature, it is inconvenient to compute during the solving process. To address this, we can use the C-C transformation to convert it into the following linear model:

$$e_{k\max}^{1} = \max\left(\sum_{d=1}^{D} w_d z_{dk} + \sum_{r=1}^{s_1} u_r^1 y_{rk}^1 + u_k^1\right)$$

$$s.t. \sum_{i=1}^{m_1} v_i^1 x_{ik}^1 = 1,$$

$$\sum_{d=1}^{D} w_d z_{dj} + \sum_{r=1}^{s_1} u_r^1 y_{rj}^1 + u_k^1 - \sum_{i=1}^{m_1} v_i^1 x_{ij}^1 \le 0, \forall j,$$

$$\sum_{r=1}^{s_2} u_r^2 y_{rj}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rj}^b + u_k^2 - \sum_{i=1}^{m_2} v_i^2 x_{ij}^2 + \sum_{d=1}^{D} w_d Z_{dj} \le 0, \forall j,$$

$$u_r^1, u_r^2, u_r^b, v_i^1, v_i^2, w_d \ge 0, \forall i, r, d,$$

$$u_k^1, u_k^2 free. \tag{3}$$

Since $e_k^1 \in \left[0, e_{k\max}^1\right]$, when calculating the overall efficiency of the two stages, e_k^1 can be considered as capable of varying within a certain range, and this value is known. Therefore, model (1) can be written as:

$$e_k = \max e_k^1 * \frac{\sum_{r=1}^{s_2} u_r^2 y_{rk}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rk}^b + u_k^2}{\sum_{i=1}^{m_2} v_i^2 x_{ik}^2 + \sum_{d=1}^{D} w_d z_{dk}}$$

$$s.t. \frac{\sum_{d=1}^{D} w_d z_{dj} + \sum_{r=1}^{s_1} u_r^1 y_{rj}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ij}^1} \le 1, \forall j,$$

$$\frac{\sum_{r=1}^{s_2} u_r^2 y_{rj}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rj}^b + u_k^2}{\sum_{i=1}^{m_2} v_i^2 x_{ij}^2 + \sum_{d=1}^{D} w_d z_{dj}} \le 1, \forall j,$$

$$\frac{\sum_{d=1}^{D} w_d z_{dk} + \sum_{r=1}^{s_1} u_r^1 y_{rk}^1 + u_k^1}{\sum_{i=1}^{m_1} v_i^1 x_{ik}^1} = e_k^1,$$

$$e_k^1 \in \left[0, e_{k\max}^1\right],$$

$$u_r^1, u_r^2, u_r^b, v_i^1, v_i^2, w_d \ge 0, \forall i, r, d,$$

$$u_k^1, u_k^2 free. \tag{4}$$

Model (4) can be transformed into the following model via C-C transformation:

$$
\begin{aligned}
& e_k = \max\ e_k^1 * \left(\sum_{r=1}^{s_2} u_r^2 y_{rk}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rk}^b + u_k^2 \right) \\
& s.t. \sum_{i=1}^{m_2} v_i^2 x_{ik}^2 + \sum_{d=1}^{D} w_d z_{dk} = 1, \\
& \sum_{d=1}^{D} w_d z_{dj} + \sum_{r=1}^{s_1} u_r^1 y_{rj}^1 + u_k^1 - \sum_{i=1}^{m_1} v_i^1 x_{ij}^1 \le 0, \forall j, \\
& \sum_{r=1}^{s_2} u_r^2 y_{rj}^2 + \sum_{r=1}^{B} u_r^b \overline{y}_{rj}^b + u_k^2 - \sum_{i=1}^{m_2} v_i^2 x_{ij}^2 + \sum_{d=1}^{D} w_d z_{dj} \le 0, \forall j, \\
& \sum_{d=1}^{D} w_d z_{dk} + \sum_{r=1}^{s_1} u_r^1 y_{rk}^1 + u_k^1 - e_k^1 * \sum_{i=1}^{m_1} v_i^1 x_{ik}^1 = 0, \\
& e_k^1 \in \left[0, e_{k\max}^1\right], \\
& u_r^1, u_r^2, u_r^b, v_i^1, v_i^2, w_d \ge 0, \forall_i, r, d, \\
& u_k^1, u_k^2 free.
\end{aligned} \tag{5}
$$

3. Data Source and Construction of Indicator System

In order to comprehensively and objectively assess the operational efficiency of China's basic old-age insurance system for urban and rural residents, the selection of indicators is crucial. Table 1 lists the input and output indicators chosen in this study.

Table 1: Indicator System for Inputs and Outputs

Stage	Indicator Category	Specific Indicators	Unit	Calculation Formula
Fundraising Stage	Input Indicators	Fund Income	100 million Yuan	——
		Number of Insured Individuals	10,000 people	——
	Intermediate Indicator:	Accumulated Fund Balance	100 million Yuan	——
Operating Stage	Output Indicators	Number of Actual Beneficiaries	10,000 people	——
		Fund Expenditure	100 million Yuan	——
		Participation Rate	%	Number of Insured Individuals/Number of Eligible Individuals

This study focuses on the research of the urban and rural residents' basic old-age insurance system in 31 provincial-level units in China from 2014 to 2021. Based on the identified input and output indicators, this article measures the operational efficiency of China's urban and rural residents' basic old-age insurance system using data from the "China Statistical Yearbook" and various provinces and cities, as shown in table 2.

Table 2: Data on the Evaluation Indicator System for the Operational Efficiency of China's Urban and Rural Residents' Basic Old-Age Insurance System

Province	Fund Income (100 million yuan)	Number of Insured Individuals (10,000 people)	Accumulated Fund Balance (100 million yuan)	Number of Actual Beneficiaries Receiving Benefits (10,000 people)	Fund Expenditure (100 million yuan)	Participation Rate (%)
Beijing	53.03	201.76	149.55	76.59	44.48	0.83
Anhui	189.66	3444.16	393.85	907.83	116.41	0.75
Fujian	99.09	1528.30	163.96	449.59	73.08	0.63
Gansu	71.06	1309.31	167.96	306.41	41.05	0.68
Guangdong	228.18	2583.05	410.61	841.26	197.29	0.62
Guangxi	106.04	2029.36	158.21	563.06	76.80	0.57
Guizhou	67.91	1775.31	115.43	448.66	51.01	0.62
Hainan	28.14	299.80	74.31	73.31	16.01	0.58
Hebei	181.91	3489.34	339.40	1004.58	127.54	0.68
Henan	241.60	5056.64	461.25	1357.69	173.99	0.71
Heilongjiang	46.45	868.68	82.11	263.03	35.63	0.64
Hubei	154.18	2283.55	299.13	692.66	102.66	0.65
Hunan	159.41	3379.90	295.66	889.54	116.61	0.72
Jilin	39.53	688.60	61.65	245.84	30.53	0.60
Jiangsu	349.66	2360.88	611.74	1063.28	275.66	0.66
Jiangxi	97.59	1932.53	205.89	471.89	59.39	0.65
Liaoning	69.40	1044.81	72.33	400.83	62.30	0.69
Inner Mongolia	60.54	759.94	95.01	223.11	47.50	0.60
Ningxia	13.61	204.26	30.94	39.65	8.91	0.58
Qinghai	18.11	245.61	39.55	41.91	9.89	0.65
Shandong	400.53	4558.31	925.21	1476.14	259.75	0.73
Shanxi	82.89	1584.35	194.44	398.40	53.75	0.69
Shaanxi	109.01	1747.11	219.73	487.98	77.10	0.69
Shanghai	70.61	77.93	81.46	50.46	66.11	0.66
Sichuan	246.41	3132.08	467.25	1109.20	174.28	0.67
Tianjin	62.34	148.56	234.31	79.66	37.84	0.58
Tibet	9.49	163.91	23.04	22.11	5.28	0.58
Xinjiang	34.26	652.35	87.65	109.88	19.86	0.52
Yunnan	157.31	2330.23	303.64	513.81	63.80	0.62
Zhejiang	207.36	1211.41	186.86	540.35	167.90	0.65
Chongqing	69.70	1133.55	131.14	361.86	55.18	0.69
Maximum Value	400.53	5056.64	925.21	1476.14	275.66	0.83
Minimum Value	9.49	77.93	23.04	22.11	5.28	0.52
Average Value	120.16	1684.70	228.49	500.34	85.41	0.65

When applying the DEA model, it is necessary to satisfy the assumption of "same directionality," which means that an increase in inputs does not lead to a decrease in outputs. Table 3 presents the results of the Pearson correlation test. From the table, we observe that there is a positive correlation between fund income and factors such as insurance enrollment, fund expenditure, participation rate, number of recipients of benefits, and fund accumulated balance. Furthermore, all the factors have passed the two-tailed test, achieving a significance level of 1%, which supports the "same directionality" assumption. This indicates that the selected input-output evaluation indicators are reasonable.

Table 3: Pearson Correlation Test Results for Input-Output Indicators

	Fund Income	Insurance Enrollment	Fund Accumulated Balance
Actual number of beneficiaries	0.857** (0.000)	0.952** (0.000)	0.729** (0.000)
Fund expenditure	0.980** (0.000)	0.716** (0.000)	0.907** (0.000)
Participation rate	0.561** (0.000)	0.312** (0.000)	0.613** (0.000)

Note: ** and * represent significance levels of 1% and 5%, respectively.

4. Efficiency Measurement

In this study, the super-efficiency two-stage DEA model was employed, and the MAXdea8.0 software was used for calculations to analyze the comprehensive efficiency of the operation of the urban and rural residents' basic pension insurance system in 31 regions in China from 2014 to 2021. The results are shown in the following Table 4:

From Table 4, it can be seen that in the fundraising stage, in terms of regions, the total average efficiency value of China's urban and rural residents' basic pension insurance system is 0.791. The average efficiency value for the eastern region is 0.808, for the central region is 0.765, and for the western region is 0.789. The average efficiency values for the eastern and western regions in this stage are higher than the overall efficiency value, but the average efficiency value for the central region is the lowest, lower than the overall efficiency value, indicating that the low efficiency value in this stage is mainly caused by the central region. From the perspective of provinces, Beijing, Tianjin, Shanghai, Ningxia, Tibet, and other regions have higher efficiency values in the fundraising stage, while Guangxi, Guizhou, and Liaoning have relatively lower efficiency. From a temporal perspective, from 2014 to 2021, the average total efficiency value of China's urban and rural residents' basic pension insurance system in the fundraising stage has remained relatively stable. Further analysis reveals that this may be due to lower pure technical efficiency in the central region and the presence of resource allocation issues, which affect the nationwide pure technical efficiency of the urban and rural pension insurance system. The operational scale efficiency of China's urban and rural residents' basic pension insurance system is the main factor in comprehensive technical efficiency change, and it is more pronounced that in the central region, there is still waste of redundant resources, resulting in low operational scale efficiency of the urban and rural pension insurance system in the central region, thereby affecting the overall efficiency of the nationwide urban and rural pension insurance system.

Table 4: Efficiency Measurement Results of China's Urban and Rural Residents' Basic Pension Insurance System Operation

	Province	Overall Efficiency Value	Stage1	Stage2
Eastern Region	Beijing	0.650	0.909	0.720
	Tianjin	0.531	0.967	0.549
	Hebei Province	0.651	0.759	0.858
	Liaoning Province	0.665	0.688	0.966
	Shanghai	0.721	0.905	0.796
	Jiangsu Province	0.653	0.789	0.828
	Zhejiang Province	0.647	0.713	0.908
	Fujian Province	0.597	0.753	0.794
	Shandong Province	0.705	0.798	0.883
	Guangdong Province	0.618	0.781	0.791
	Hainan Province	0.517	0.831	0.633
	mean	0.632	0.808	0.793
Central Region	Shanxi Province	0.622	0.798	0.780
	Jilin Province	0.599	0.742	0.808
	Heilongjiang Province	0.615	0.771	0.798
	Anhui Province	0.713	0.766	0.932
	Jiangxi Province	0.610	0.767	0.799
	Henan Province	0.693	0.761	0.910
	Hubei Province	0.618	0.768	0.806
	Hunan	0.701	0.749	0.936
	mean	0.646	0.765	0.846
Western Region	Inner Mongolia Autonomous Region	0.552	0.759	0.727
	Guangxi Zhuang Autonomous Region	0.586	0.720	0.816
	Chongqing Municipality	0.639	0.753	0.857
	Sichuan Province	0.647	0.777	0.832
	Guizhou Province	0.604	0.728	0.836
	Yunnan Province	0.569	0.782	0.730
	Tibet Autonomous Region	0.499	0.859	0.630
	Shaanxi Province	0.632	0.776	0.814
	Gansu Province	0.611	0.803	0.762
	Qinghai Province	0.503	0.824	0.613
	Ningxia Hui Autonomous Region	0.503	0.858	0.587
	Xinjiang Uyghur Autonomous Region	0.497	0.833	0.598
	mean	0.570	0.789	0.734

In the operational stage, in terms of regions, the total average efficiency value of China's urban and rural residents' basic pension insurance system is 0.781. The average efficiency value for the eastern region is 0.793, for the central region is 0.846, and for the western region is 0.734. The average efficiency values for the eastern and central regions in this stage are higher than the overall efficiency value, but the average efficiency value for the western region is lower than the overall efficiency value. The western region has the lowest average efficiency value, indicating that the low efficiency value in this stage is mainly caused by the western region. Looking at the efficiency values in the operational stage of various provinces, Zhejiang, Hunan, Anhui, Henan, Liaoning, Xinjiang, Ningxia, Qinghai, and Tianjin have lower efficiency values compared to other regions. From a temporal perspective, from 2014 to 2021, the average total efficiency value of China's urban and rural residents' basic pension insurance system in the operational stage showed a trend of initially decreasing and then increasing. This is largely due to the significant increase in residents' participation in the insurance system after the merger of urban and rural pension systems. From the perspective of efficiency values, this result is likely due to insufficient investment and unreasonable resource allocation in the western region, leading to a decrease in the pure technical efficiency of China's urban and rural residents' basic pension insurance system. Within the country, the pure technical efficiency of China's urban and rural residents' basic pension insurance system is influenced by the pure technical efficiency in the central and western regions. Therefore, it is necessary to improve the pure technical efficiency of the urban and rural residents' basic pension insurance system in each region based on specific circumstances.

5. Dynamic Efficiency Analysis based on Malmquist Index

In the above two-stage network DEA approach for super-efficiency analysis, the static DEA efficiency of China's urban and rural pension insurance system operation was studied. In order to calculate the efficiency of multiple inputs and outputs in a dynamic and longitudinal manner using panel data of decision-making units in different time periods, the DEA-Malmquist index method will be applied to dynamically analyze the total factor productivity. By combining static and dynamic analyses, the DEA-Malmquist index model can highlight the dynamic comparison between inputs and outputs, which is helpful for a better measurement of the efficiency of China's urban and rural pension insurance system operation and to understand the efficiency gap among different regions. Furthermore, decomposing total factor productivity can further identify the factors contributing to changes in total factor productivity, thereby conducting a more detailed analysis of the factors affecting the efficiency of China's urban and rural residents' basic pension insurance system operation and making the evaluation results more scientifically reasonable.

Table 5: Efficiency Results in the Fundraising and Operational Stages (Nationwide)

Year	Total Efficiency Value	Efficiency Value in the Fundraising Stage	Efficiency Value in the Operational Stage
2014	0.611	0.790	0.782
2015	0.610	0.791	0.781
2016	0.610	0.791	0.781
2017	0.610	0.791	0.781
2018	0.610	0.791	0.780
2019	0.609	0.791	0.780
2020	0.609	0.791	0.780
2021	0.609	0.791	0.779
Mean	0.610	0.791	0.781

In the fundraising stage, Table 5 shows that the changes in total factor productivity reflect the dynamic trend of efficiency in China's urban and rural residents' basic pension insurance system operation. The average total factor productivity of China's urban and rural residents' basic pension insurance system from 2014 to 2021 is 1.033, indicating an increase of 3.3% in total factor productivity. The efficiency of China's urban and rural residents' basic pension insurance system operation has shown an upward trend from 2014 to 2021. However, the indices that drive the annual changes in total factor productivity are not consistent. The main reasons for positive total factor productivity indices in 2014-2015, 2017-2018, 2018-2019, and 2020-2021 in China's urban and rural residents' basic pension insurance system operation are positive overall efficiency, technological progress, and scale efficiency. The main reasons for negative total factor productivity indices in 2015-

2016 and 2019-2020 in China's urban and rural residents' basic pension insurance system operation are negative overall efficiency, technological progress, pure technical efficiency, and scale efficiency. The main reasons for positive total factor productivity index in 2016-2017 in China's urban and rural residents' basic pension insurance system operation are positive overall efficiency, technological progress, pure technical efficiency, and scale efficiency.

Table 6: Total Factor Productivity and Decomposed Efficiency of China's Urban and Rural Residents' Basic Pension Insurance System in the Fundraising Stage

Year	Total Factor Productivity(Tfpch)	Overall Efficiency(Effch)	Technological Progress(Tech)	Pure Technical Efficiency(Pech)	Scale Efficiency(Sech)
2014-2015	1.042	1.022	1.020	0.999	1.023
2015-2016	0.982	0.992	0.990	0.993	0.999
2016-2017	1.008	1.004	1.004	1.000	1.004
2017-2018	1.147	1.071	1.071	0.992	1.080
2018-2019	1.017	1.009	1.008	0.990	1.019
2019-2020	0.973	0.987	0.986	0.994	0.993
2020-2021	1.060	1.030	1.029	0.996	1.034
mean	1.033	1.016	1.015	0.995	1.022

Table 7: Total Factor Productivity and Decomposed Efficiency of China's Urban and Rural Residents' Basic Pension Insurance System in the Operational Stage

Year	Total Factor Productivity(Tfpch)	Overall Efficiency(Effch)	Technological Progress(Tech)	Pure Technical Efficiency(Pech)	Scale Efficiency(Sech)
2014-2015	1.035	1.018	1.017	1.022	0.996
2015-2016	0.988	0.994	0.994	1.003	0.991
2016-2017	1.001	1.001	1.000	0.999	1.002
2017-2018	1.101	1.051	1.048	1.017	1.033
2018-2019	1.028	1.014	1.014	1.002	1.012
2019-2020	1.027	1.014	1.013	1.016	0.998
2020-2021	1.054	1.027	1.026	1.018	1.009
mean	1.033	1.017	1.016	1.011	1.006

In the operational stage, Table 6 and 7 reveals that the average total factor productivity of China's urban and rural residents' basic pension insurance system from 2014 to 2021 is 1.033, indicating an increase of 3.3% in total factor productivity. The efficiency of China's urban and rural residents' basic pension insurance system operation has shown an upward trend from 2014 to 2021. The main reasons for positive total factor productivity indices in 2014-2015 and 2019-2020 are positive overall efficiency, technological progress, and pure technical efficiency. The main reason for negative total factor productivity index in 2015-2016 is negative overall efficiency, technological progress, and scale efficiency. The main reason for positive total factor productivity index in 2016-2017 is positive overall efficiency, technological progress, and scale efficiency. The main reasons for positive total factor productivity indices in 2017-2018, 2018-2019, and 2020-2021 are positive overall efficiency, technological progress, pure technical efficiency, and scale efficiency.

Through a comprehensive analysis of the different periods from 2014 to 2021, it can be observed that technological progress and pure technical efficiency have a significant impact on the dynamic changes in the efficiency of the urban and rural residents' basic pension insurance system. This also reflects that there are significant deficiencies in the innovation, development, and application of modern management techniques and the utilization of resources in China's basic pension insurance system for urban and rural residents. However, in some time periods, the scale efficiency index also has a negative impact on the changes in total factor productivity, indicating issues with resource allocation in the development of the urban and rural residents' basic pension insurance system.

6. Conclusions and Recommendations

6.1. Conclusions

Using the two-stage network DEA model, this study conducted a systematic analysis of the efficiency values of the urban and rural residents' basic pension insurance system in 31 provinces, municipalities, and autonomous regions in China from 2014 to 2021. The following conclusions are drawn:

First, the results of the static analysis indicate that in the fundraising stage, the low overall efficiency values are primarily caused by the central region. In the operational stage, the lowest average total efficiency value is found in the western region.

Second, the results of the dynamic analysis show that in both the fundraising and operational stages, the average total factor productivity of China's urban and rural residents' basic pension insurance system from 2014 to 2021 is 1.033, indicating an average increase of 3.3% in total factor productivity.

Third, through a comprehensive analysis of the data from 2014 to 2021, it is found that technological progress and pure technical efficiency have a significant impact on the operational efficiency of China's urban and rural residents' basic pension insurance system.

6.2. Recommendations

(1) Improving the management mechanism for the financial funds of urban and rural residents' pension insurance

There is a strong negative correlation between the proportion of fiscal expenditure and the operational efficiency of the urban and rural residents' basic pension insurance system measured by the Theil index. Therefore, it is necessary to continue reform efforts, improve the financial management system, and establish an effective management mechanism for the financial funds of urban and rural residents' pension insurance. This mechanism should optimize the scale and structure of fiscal expenditure for the basic pension insurance, enhance the scale efficiency of the system's operation, and reduce the uneven development of the operational efficiency across regions.

(2) Promoting overall economic stability and regional coordinated development.

The level of economic development significantly influences the efficiency of fund collection and utilization in China's urban and rural residents' pension insurance. Promoting stable overall economic growth is a necessary approach to further enhance the operational efficiency of the pension insurance system. Additionally, promoting regional coordinated development helps to reduce regional disparities in fund collection and utilization efficiency.

(3)Strengthening overall planning and management of pension funds

By adjusting the current balance of pension insurance funds among different regions at the national level, timely and full payment of pension benefits can be ensured. This can address the structural contradictions in fund allocation and provide greater security for pension benefits in impoverished areas. Led by the Ministry of Human Resources and Social Security, unified management of national fiscal appropriations should be strengthened to ensure the safety and smooth mobilization of fiscal funds.

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