Measurement and analysis of the total factor productivity of the three major industries in Tianjin

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Abstract. Based on relevant data on the primary, secondary, and tertiary industries in Tianjin from 2009–2019, combined with the decomposition of the DEA-Malmquist index, the total factor productivity (TFP) of the three major industries in Tianjin in 2009–2019 and its decomposition were calculated using DEAP2.1 software. Also, the TFP was comprehensively analyzed. The results showed that the TFP of Tianjin's three major industries showed a downward trend in 2009–2019, and the most important reason for this phenomenon was the decline in technological progress. When Tianjin develops its three major industries, it should focus on strengthening technological innovation and establishing strict and standardized management systems, rules, and regulations to promote a significant increase in TFP and the steady and high-quality development of its economy.

1 Introduction

The driving force of high-quality development is increased total factor productivity (TFP). A report by the 20th National Congress of the Communist Party of China emphasized the need to focus on improving TFP and promoting high-quality development. In essence, TFP is the efficiency of resource allocation, and its improvement is key to promoting industrial upgrading and ensuring the sustainable development of productivity. As the economic center of the north, in recent years, Tianjin has taken "structural adjustment, transformation, and upgrading" as the main line and focused on "making up for weaknesses," "complementing weaknesses," "upgrading," "laying the foundation," and "benefiting the people," laying the foundation for a new round of high-quality development and achieving solid results. Tianjin's transformation is actually a process of urban industrial restructuring and industrial transformation and upgrading, and is representative of China's economic transformation from "factor driven" to "innovation driven."

Many scholars have studied TFP at the enterprise level in terms of its measurement and application. Miao [1] used a threshold effect model to analyze the nonlinear relationship between credit risk and factor productivity. Wang [2] analyzed the impact of green

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investment on TFP. And many previous macro-level estimates and analyses of TFP were based on a single industry. Zhang [3] measured the TFP of agriculture in 31 provinces and cities in China and established fixed effect and spatial dubin models to empirically analyze the impact of digital financial inclusion on agricultural TFP. Feng [4] used a generalized method of moments (GMM) dynamic panel econometric model incorporating mediation effects and analyzed how the spatial mismatch of industrial land affects industrial TFP through industrial agglomeration in three dimensions: national, regional, and mismatch types. Wang [5] used panel data from 284 prefectures and cities in China from 2012 to 2019 to empirically study the impact of logistics industry clusters on TFP in the manufacturing industry by constructing a spatial econometric model. In addition, many scholars have conducted research on green total factor productivity (GTFP). Hong [6] based on the Peking University Digital Financial Inclusion Index and 2011-2018 provincial panel data discuss the mechanism of digital financial inclusion on agricultural GTFP from both theoretical and empirical perspectives. Tong [7] investigated the role of Environmental regulation (ER), green finance (GF), foreign direct investment (FDI), and increased investment in green technologies (IGT) on GTFP in 27 Chinese provinces from 2010 to 2021. Based on the comprehensive index of green finance development, Chen [8] examined the impact of green finance, financial development and green technology innovation on GTFP in 28 Chinese provinces in 2011-2021 by using non-parametric data envelope analysis and direction distance function model.

The above research provides rich theories and perspectives on the measurement of TFP in China; however, there is still a lack of systematic and in-depth empirical research on the measurement of TFP in the three major industries on a regional scale. This study considered the three major industries in Tianjin as the research object; used the DEA-Malmquist index method to measure the TFP of these industries in Tianjin from 2009 to 2019; analyzed the contribution of technological progress, technical efficiency, pure technology efficiency, and scale efficiency to TFP through the measurement results; and explored the dynamic changes in the TFP of the three major industries in Tianjin. This paper puts forward relevant suggestions to contribute to the high-quality development of Tianjin's economy.

2 Research design

2.1 Measurement method

The DEA-Malmquist index method combines the data envelopment analysis (DEA) and Malmquist index methods. DEA is a method used to evaluate whether the scale of multiple inputs and outputs is reasonable, as it is a ratio representing the longitudinal dynamic change of productivity of the research object, which refers to the ratio of the distance function of two different periods. The TFP of the research object can be obtained by solving the distance function. Combining the Malmquist index method with the DEA allows for efficiency comparisons over time [9]. Therefore, the DEA-Malmquist method is generally applied to input and output analyses, especially dynamic efficiency analyses of productivity. The DEA-Malmquist index method was used to analyze TFP, and the specific measurement process was based on the measurement steps of a scholar named Nana Xu [10].

First, the input-output function is determined, and the function is defined as output oriented. Assuming that there are n decision units with x inputs and y outputs per period, let $I = (I_1, I_2, I_3, ..., I_x)$ be an input function and $O = (O_1, O_2, O_3, ..., O_y)$ be an output function.

Second, the output-oriented DEA-Malmquist index M is constructed to characterize the change in factor productivity from period s to period s+1 (see Equation (1)).

$$M(I_s,O_s,I_{s+1},O_{s+1}) = \sqrt{\frac{D^s(I_{s+1},O_{s+1})}{D^s(I_s,O_s)} * \frac{D^{s+1}(I_{s+1},O_{s+1})}{D^{s+1}(I_s,O_s)}} \tag{1}$$

Here, D^s and D^{s+1} represent the current efficiency level represented by the s+1 technology, and when M>1, TFP increases, which may be an improvement brought about by technological progress or efficiency improvement. Conversely, TFP decreases and M=1 indicates no change.

Assuming that the return to scale is constant, this indicator can be broken down into two parts—technological progress efficiency change (techch) and technical efficiency change (effch)—to determine whether technological innovation exists and whether technology has left the production frontier (see Equation (2)).

$$\begin{aligned} M(I_s,O_s,I_{s+1},O_{s+1}) &= \frac{D_c^{s+1}(I_{s+1},O_{s+1})}{D_c^s(I_s,O_s)} \times \sqrt{\frac{D_c^s(I_{s+1},O_{s+1})}{D_c^{s+1}(I_{s+1},O_{s+1})} * \frac{D_c^s(I_s,O_s)}{D_c^{s+1}(I_s,O_s)}} \\ &= effch \times techch \end{aligned} \tag{2}$$

If effch and tech are larger than 1, it means that the utilization efficiency of technology has improved, and the technological progress of the entire industry has improved. If they are less than 1, the efficiency of technology utilization declines, and the technology of the entire industry declines. If they are equal to 1, nothing has changed.

Assuming that the return on scale is variable, the change in technical efficiency (effch) can be broken down into two types: pure technical efficiency change (pech) and change in scale efficiency (sech) (see Equation 3).

$$\begin{aligned} &M(I_s,O_s,I_{s+1},O_{s+1}) \\ &= \frac{D_v^{s+1}(I_{s+1},O_{s+1})}{D_v^s(I_s,O_s)} \times \frac{D_v^s(I_s,O_s)/D_c^s(I_s,O_s)}{D_v^{s+1}(I_{s+1},O_{s+1})/D_c^{s+1}(I_{s+1},O_{s+1})} \\ &\times \sqrt{\frac{D_c^s(I_{s+1},O_{s+1})}{D_c^{s+1}(I_{s+1},O_{s+1})} * \frac{D_c^s(I_s,O_s)}{D_c^{s+1}(I_s,O_s)}} = pech \times sech \times techch \end{aligned} \tag{3}$$

In summary, when techch>1, it indicates technological progress, indicating that the change in the efficiency of technological progress promotes the improvement of TFP; when techch<1, it indicates technological regression, indicating that changes in the efficiency of technological progress have led to a decline in TFP. When effch>1, the technology is effective, indicating that the change in technological efficiency promotes the growth of TFP. When effch<1, it means that the technology is invalid, indicating that the change in technological efficiency has led to a decrease in TFP. The influence of sech and pech is reflected onto effch. When sech >1, it means that the actual production scale is close to the optimal production scale; when sech <1, it means that the actual production scale is far from the optimal production scale; when pech >1, it means that the management level is improved and efficiency increases; and when pech <1, it means that there is a problem in management and efficiency is reduced.

2.2 Indicator selection

The DEA model has particularly high requirements for variable indicators because the selection of indicators has a great impact on the measured results. This study took the three major industries in Tianjin as the decision-making unit and selected statistics from 2009 to

2019. Referring to previous relevant research, capital and labor were taken as input variables, the amount of fixed asset investment was used as the capital variable index based on the availability of data, and the number of employees was used as the labor variable index. The output variable was selected using the respective annual GDP of the three major industries in Tianjin, and the base period of 2009 was converted into actual GDP.

3 Analysis of the results

3.1 TFP change (tfpch) analysis

Table 1 shows the tfpch index values of the three major industries in Tianjin from 2009 to 2019, calculated and sorted using the DEAP2.1 software in an output-oriented manner. Combined with Table 1, it can be seen that during 2009−2019, Tianjin's primary industry tfpch fluctuated greatly, especially in 2015−2016, when tfpch dropped directly to 0.419, becoming the smallest index value in 10 dynamic intervals of 2009−2010 and 2012−2013. In 2016−2017 and 2017−2018, the tfpch of the primary industry was greater than 1, and the rest of the years were less than 1, with a mean value of 0.897, less than 1, which showed a lack of efficiency. The tfpch of the secondary industry in the period 2015−2018 was greater than 1, and the rest of the years were less than 1, with an average value of 0.904, which is less than 1, indicating a lack of efficiency. The tfpch of the tertiary industry in all years was less than 1, indicating that the TFP level of the tertiary industry in the years between 2009 and 2019 decreased from the level of the previous year, with an average value of 0.915, less than 1, which was manifested as a lack of efficiency.

Table 1. This is tfpch index of the three major industries in Tianjin from 2009 to 2019.

Industry	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Mean
Primary	1.095	0.865	0.885	1.082	0.886	0.852	0.419	1.076	1.123	0.970	0.897
Secondary	0.850	0.948	0.872	0.891	0.926	0.926	1.013	1.084	1.036	0.599	0.904
Tertiary	0.949	0.997	0.927	0.938	0.899	0.862	0.958	0.989	0.947	0.719	0.915

3.2 Analysis of changes in the rate of technological progress (techch)

Table 2 shows the 2009−2019 techch index values of the three major industries in Tianjin that were measured and sorted out using DEAP2.1 software in an output-oriented manner. Combined with Table 2, it can be seen that during 2009−2019, the techch fluctuation in the primary industry in Tianjin was significantly higher than that in the secondary and tertiary industries, and the techch of the primary industry in 2009−2010, 2012−2013, 2016−2017, and 2017−2018 was greater than 1, and less than 1 in the remaining years, with an average value of 0.897, less than 1, indicating technological regression. The fluctuation trends of the secondary and tertiary industries were roughly the same; the techch of the secondary industry was more than 1 between 2015 and 2018, and less than 1 in the rest of the years. The average value was 0.904, less than 1, indicating technological regression; the tertiary industry's techch in 2016−2018 was greater than 1, the rest of the years were less than 1, and the average value was 0.905, less than 1, indicating technological regression. This shows that in Tianjin during 2009－2019, the technological progress or degree of technological innovation in the three major industries was not high.

Table 2. This is techch index of the three major industries in Tianjin from 2009 to 2019.

Industry	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Mean
Primary	1.095	0.865	0.885	1.082	0.886	0.852	0.714	1.125	1.059	0.577	0.897
Secondary	0.850	0.948	0.872	0.891	0.926	0.926	1.013	1.084	1.036	0.599	0.904
Tertiary	0.899	0.977	0.895	0.891	0.906	0.880	0.975	1.045	1.013	0.636	0.905

3.3 Analysis of changes in technical efficiency (effch)

Table 3 shows the output-oriented calculation and sorting of the 2009−2019 effch index values of the three major industries in Tianjin using DEAP2.1 software. Combined with Table 3, it can be seen that for Tianjin's primary industry, in these 11 years, 2015 was a cutoff point; before 2015, Tianjin's primary industry effch did not change; after 2015, the effch began to change from a lack of efficiency to efficiency, but its average value was equal to 1. Overall, Tianjin's primary industry's technical efficiency showed no obvious change. The effch of the secondary sector was equal to 1 during this time, indicating that technological efficiency had little impact. The effch of the tertiary industry was manifested as inefficient in half of the dynamic interval and efficient in the remaining half, but its average value was 1.012, greater than 1, in general, during this period. So, although the tertiary industry in Tianjin did not fluctuate much, its technical efficiency still rose.

Table 3. This is effch index of the three major industries in Tianjin from 2009 to 2019.

Industry	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Mean
Primary	1.000	1.000	1.000	1.000	1.000	1.000	0.586	0.957	1.061	1.681	1.000
Secondary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tertiary	1.056	1.020	1.036	1.052	0.993	0.979	0.983	0.946	0.936	1.129	1.012

3.4 Pure technical efficiency change analysis (pech)

Table 4 shows the pech index values of the three major industries in Tianjin from 2009 to 2019, calculated and sorted using DEAP2.1 software in an output-oriented manner. Combined with Table 4, it can be seen that in 2009−2019, the pech of the primary and secondary industries in Tianjin was equal to 1, indicating that there was no change in pure technical efficiency. The tertiary industry's pech was greater than 1 in 2009−2013, and there was no change in the remaining years, with an average value of 1.017, indicating that the management level improved, resulting in increased efficiency.

Table 4. This is pech index of the three major industries in Tianjin from 2009 to 2019.

Industry	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Mean
Primary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Secondary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tertiary	1.080	1.035	1.057	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.017

3.5 Analysis of changes in scale efficiency (sech)

Table 5 shows the output-oriented calculation and sorting of the 2009−2019 sech index values of the three major industries in Tianjin using DEAP2.1 software. Combined with

Table 5, it can be seen that the sech change of the primary and secondary industries in Tianjin was the same as the change in effch; for the primary industry in Tianjin, in these 11 years, 2015 was a dividing point. Before 2015, Tianjin's primary industry sector did not change; after 2015, sech began to change from a lack of efficiency to efficiency, but its average value was equal to 1, and the overall Tianjin primary industry scale efficiency showed no obvious change. The sech of the secondary sector was equal to 1 during this time, indicating that the efficiency of the scale had little impact. The sech fluctuation in the tertiary industry was not large, with an average value of 0.995, which is less than 1, indicating that the actual production scale was far from the optimal production scale.

Table 5. This is sech index of the three major industries in Tianjin from 2009 to 2019.

Industry	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Mean
Primary	1.000	1.000	1.000	1.000	1.000	1.000	0.586	0.957	1.061	1.681	1.000
Secondary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tertiary	0.978	0.985	0.980	1.052	0.993	0.979	0.983	0.946	0.936	1.129	0.995

3.6 Summary

From this study, it can be concluded that the TFP of the three major industries in Tianjin declined from 2009 to 2019. Tables 6, 7, and 8 show the TFP changes of the three major industries in Tianjin from 2009 to 2019, measured and sorted using DEAP2.1 software, respectively. The average TFP of the primary industry was 0.897; it has declined by 10.3% because technological efficiency has not changed. The main reason for this phenomenon is the decline in technological progress in the primary industry, as shown in Table 6. The average TFP of the secondary industry was 0.904, with a decrease of 9.6%. Because technological efficiency has not changed, the main hindrance factor is the technological progress of the secondary industry, as shown in Table 7. The tertiary industry's average TFP was 0.915, with a decline of 8.5%. The tertiary industry's technology efficiency change index was 1.012, and the technological progress change index was 0.905. Although the rise in technological efficiency had a promoting effect on TFP, the rate of rise was much lower than the speed of technological regression; therefore, the main reason for the reduction in TFP in the tertiary industry was technological progress, as shown in Table 8. In summary, the change in technological progress efficiency was the most important factor affecting the dynamic change in the TFP of the three major industries in Tianjin, indicating that the degree of technological innovation in Tianjin is far from sufficient.

Table 6. Breakdown of TFP changes in the primary industry in Tianjin from 2009 to 2019.

Year	Effch	Techch	Pech	Sech	Tfpch
2009–2010	1.000	1.095	1.000	1.000	1.095
2010–2011	1.000	0.865	1.000	1.000	0.865
2011–2012	1.000	0.885	1.000	1.000	0.885
2012–2013	1.000	1.082	1.000	1.000	1.082
2013–2014	1.000	0.886	1.000	1.000	0.886
2014–2015	1.000	0.852	1.000	1.000	0.852
2015–2016	0.586	0.714	1.000	0.586	0.419
2016–2017	0.957	1.125	1.000	0.957	1.076
2017–2018	1.061	1.059	1.000	1.061	1.123
2018–2019	1.681	0.577	1.000	1.681	0.970
Mean	1.000	0.897	1.000	1.000	0.897

Table 7. Breakdown of TFP changes in the secondary industry in Tianjin from 2009 to 2019.

Year	effch	techch	pech	sech	tfpch
2009–2010	1.000	0.850	1.000	1.000	0.850
2010–2011	1.000	0.948	1.000	1.000	0.948
2011–2012	1.000	0.872	1.000	1.000	0.872
2012–2013	1.000	0.891	1.000	1.000	0.891
2013–2014	1.000	0.926	1.000	1.000	0.926
2014–2015	1.000	0.926	1.000	1.000	0.926
2015–2016	1.000	1.013	1.000	1.000	1.013
2016–2017	1.000	1.084	1.000	1.000	1.084
2017–2018	1.000	1.036	1.000	1.000	1.036
2018–2019	1.000	0.599	1.000	1.000	0.599
Mean	1.000	0.904	1.000	1.000	0.904

Table 8. Breakdown of TFP changes in the tertiary industry in Tianjin from 2009 to 2019.

Year	effch	techch	pech	sech	tfpch
2009–2010	1.056	0.899	1.080	0.978	0.949
2010–2011	1.020	0.977	1.035	0.985	0.997
2011–2012	1.036	0.895	1.057	0.980	0.927
2012–2013	1.052	0.891	1.001	1.052	0.938
2013–2014	0.993	0.906	1.000	0.993	0.899
2014–2015	0.979	0.880	1.000	0.979	0.862
2015–2016	0.983	0.975	1.000	0.983	0.958
2016–2017	0.946	1.045	1.000	0.946	0.989
2017–2018	0.936	1.013	1.000	0.936	0.947
2018–2019	1.129	0.636	1.000	1.129	0.719
Mean	1.012	0.905	1.017	0.995	0.915

4 Conclusions and recommendations

Changes in technological progress affect changes in TFP, determine the long-term development of an industry, and play an important role in promoting economic growth. In 2009−2019, the technological progress efficiency change index of Tianjin's three major industries had an average of less than 1 (see Table 2), manifested as technological regression. This showed that the decline in technological progress efficiency eventually became the biggest factor affecting the improvement of the TFP of the three major industries in Tianjin. Therefore, Tianjin should strengthen technological innovation and strive to enhance the competitiveness of its three major industries in terms of technological progress.

Although the impact of technological efficiency changes on TFP was not obvious in the results of this study, Tianjin should also promote increased technological efficiency so that technological efficiency and technological progress interact, jointly drive the growth of TFP in its three major industries, and promote the development of its economy.

Pure technical efficiency means that when the enterprise is at its best production scale, management means, rules, and regulations impact TFP. The pure technical efficiency of Tianjin's primary and secondary industries in 2009−2019 was equal to 1 (see Table 4). Pure technical efficiency had no impact on the technical efficiency of Tianjin's primary and secondary industries, indicating that they may have management problems. Therefore, in the process of development, Tianjin's primary and secondary industries should establish more complete rules, regulations, and management systems to promote the improvement of technological efficiency and bring positive effects to TFP. The average pure technical efficiency of the tertiary industry was greater than 1 (see Table 4), but its index value was still very small, which shows that there are still some problems in the system and management of the tertiary industry in Tianjin, so more efforts should be made to improve its pure technical efficiency.

Scale efficiency has an impact on how changes in the size of the enterprise itself affect efficiency. This indicator was used to measure whether the three major industries were in an optimal production state during 2009−2019. The average scale efficiency of the primary and secondary industries in Tianjin was equal to 1 (see Table 5); scale efficiency did not change and had no impact on technical efficiency. The average scale efficiency of the tertiary industry was less than 1 (see Table 5); the industrial production scale deviated from the optimal production scale, which may be due to the excessive scale of production in the tertiary industry, resulting in all aspects of production not being effectively coordinated. Therefore, in the process of industrial development, it is necessary to establish a production scale that suits the actual situation, improve scale efficiency, achieve economies of scale, and promote the high-quality development of the industry.

The level of TFP plays a very important role in economic development, and the decomposition and measurement of TFP can show its contribution and that of its decomposition value to promoting economic growth. This can be used to judge whether the driving force of economic growth is mainly input- or innovation-driven, providing suggestions and a basis for promoting economic growth and formulating sustainable economic development policies. Based on the DEA-Malmquist index, this study measured the TFP of the three major industries in Tianjin, analyzed their TFP and changes in their decomposition values, and found that the TFP of the three major industries in Tianjin declined from 2009 to 2019. The most important reason for this phenomenon was the decline in technological progress: Tianjin should increase technological innovation in the process of developing the three major industries, establish a standardized management system, and establish rules and regulations to improve TFP and promote the steady and high-quality development of Tianjin's economy.

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