

Efficiency Evaluation of Logistics Industry in the Beijing-Tianjin-Hebei Region under Low-Carbon Constraints Based on the DEA-Malmquist Model

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Abstract. This paper studies the logistics efficiency of the Beijing-Tianjin-Hebei region under the background of low-carbon economy from 2012 to 2017. We introduce the carbon dioxide emission into the input indicators on the basis of the pollutant input method, and we use the BCC model and Malmquist index model to make both static and dynamic efficiency evaluations of logistics industry. Also, we use the projection analysis method to analyze the root causes of DMUs with non-DEA efficiency. According to the problems of logistics efficiency in Beijing-Tianjin-Hebei region, we put forward some recommendations to help the whole region achieve collaborative development under the low-carbon environment.

1 Introduction

The Beijing-Tianjin-Hebei region is China's "capital economic circle" and the region with the largest economy scale and the greatest development potential in northern China. As the accelerator of economic development, logistics industry provides strategic industrial support for economic development, and its efficiency is often used to evaluate the development level of a country or a region¹. Data Envelopment Analysis (DEA) is a method of relative efficiency evaluation using multiple homogeneous decision-making units (DMUs), and it is widely used in logistics efficiency evaluation. Zhang et al. (2016) used the three-stage DEA method to analyze the logistics industry efficiency of 31 provinces (cities) in China from 2010 to 2014, eliminating the impact of environmental factors and random disturbances². Yu et al. (2018) took the logistics industry of the Yangtze River Economic Belt from 2008 to 2015 as the research object and used the CCR model and Malmquist index model to measure the static and dynamic logistics efficiency respectively³.

Under the trend of low-carbon economy, logistics industry, as a large energy consumption and carbon emission industry, has become the key industry of energy conservation and emission reduction. In current researches, there have been some scholars taking CO₂ emissions into account. Deng et al. (2020) used the SBM-DEA model to analyze logistics efficiency of 30 provinces in China under low carbon constraint¹; Guo et al. (2018) used the DEA-BCC model to calculate the logistics efficiency in the Beijing-Tianjin-Hebei region and used the projection analysis to analyze the non-DEA effective DMUs⁴.

At present, there are few studies of logistics efficiency in the Beijing-Tianjin-Hebei region considering CO₂

emissions. Based on the current researches, this paper introduces CO₂ emissions of logistics industry into the input indicators and analyzes both static and dynamic efficiency by the BCC model and Malmquist index model. In addition, this paper uses the projection analysis method to analyze the factors that affect logistics efficiency, so as to promote more suitable recommendations for the development of logistics industry in the Beijing-Tianjin-Hebei region.

2 Research method

2.1 DEA-BCC models

The basic model of DEA is the CCR model, which is used to calculate the technical efficiency on an assumption of the Constant Return to Scale (CRS) basis. In 1984, based on the CCR Model, Banker, Charnes & Cooper proposed an efficiency model with the Variable Return to Scale (VRS), called the input-oriented variable return to scale model (BCC model), and it decomposed technical efficiency (TE) into pure technical efficiency (PTE) and scale efficiency (SE)⁵. The BCC model is as follows:

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$$\begin{aligned}
 & \min \theta - \varepsilon \left(\sum_{r=1}^s s_r^+ + \sum_{i=1}^m s_i^- \right) \\
 \text{s.t.} & \begin{cases} \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = \theta x_{i0} \quad (i = 1, 2, \dots, m) \\ \sum_{j=1}^n \lambda_j y_{rj} - s_r^+ = y_{r0} \quad (r = 1, 2, \dots, s) \\ \sum_{j=1}^n \lambda_j = 1 \\ \lambda_j, s_r^+, s_i^- \geq 0, \forall i, r, j \end{cases} \quad (1)
 \end{aligned}$$

In the basic BCC model, DMUs can be regarded as the process of generating a certain amount of outputs with a certain amount of inputs under particular circumstances. For region j , DMU_j ($j = 1, 2, \dots, n$) has m input indicators and s output indicators. x_{ij} and y_{rj} represent the numerical value of the i th input indicator and the r th output indicator of DMU_j ($i=1, 2, \dots, m; r = 1, 2, \dots, s$) respectively. λ_j denotes the weights of the input-output indicators; s_i^- and s_r^+ are the respective slacks for the input and output variables, and ε is the non-Archimedes infinitesimal. If $\theta = 1, S^- = S^+ = 0$, it is the optimal solution, suggesting that it reaches the DEA frontier and the TE equal to 1; if $\theta = 1, S^- \neq 0$ or $S^+ \neq 0$, it indicates the weak efficiency; when $\theta < 1$, it is inefficient, and in order to achieve the optimal technical efficiency, it is necessary to analyze the projection of DEA invalid units and make some adjustments for input and output values.

2.2 Projection analysis

For DMU_t with the value of TE less than 1, the projection analysis can help to calculate the improvement direction of the DEA invalid area. Set $x_t^* = \theta_t x_t - s_t^-; y_t^* = y_t + s_t^+$, and (x_t^*, y_t^*) is the projection of the efficiency frontier for (x_t, y_t) . Then, the input redundancy Δx_t and the output inadequacy Δy_t can be expressed as:

$$\Delta x_t = x_t^* - x_t = (\theta_t - 1)x_t - s_t^- \quad (2)$$

$$\Delta y_t = y_t^* - y_t = s_t^+ \quad (3)$$

2.3 Malmquist index model

The Malmquist index model is proposed by Sten Malmquist, a Swedish economist and statistician, in 1953. Based on Sten's research, Caves et al. (1982) introduced the distance function, which reflects the Total Factor Productivity change (TFPCH) through measuring the distance between the DMU and the production frontier⁶. Fare et al. (1992) further applied it to the study of production efficiency and combined the non-parametric linear programming method with DEA theory to construct the Total Factor Productivity Malmquist index⁷. In order to avoid the randomness of time selection, the geometric mean of M_t and M_{t+1} is chosen to calculate the Malmquist index. Therefore, the Malmquist index, which measures the TFP from t to $t + 1$, can be expressed as:

$$M(x^{t+1}, y^{t+1}; x^t, y^t) = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (4)$$

If $M > 1$, the productivity increases from t to $t + 1$; if $M = 1$, the productivity remains unchanged; if $M < 1$, the productivity decreases.

The Malmquist total production efficiency change (TFPCH) can be decomposed into the technical efficiency change (EFFCH) and the technology change (TECHCH), from which the key factor affecting the change of Malmquist index can be found. The technical efficiency change is:

$$EFFCH = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \quad (5)$$

The technology change is:

$$TECHCH = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (6)$$

TECHCH can be further decomposed into pure technical efficiency change (PECH) and scale efficiency change (SECH),

$$EFFCH = PECH \times SECH \quad (7)$$

If $EFFCH > 1$, it indicates that the technical efficiency improves; otherwise, the technical efficiency declines. $TECHCH > 1$ indicates the technology progress, and the production frontier moves forward. To sum up, Malmquist index is as follows:

$$TFPCH = TECHCH \times EFFCH = TECHCH \times PECH \times SECH \quad (8)$$

3 Indicators and data

3.1 Indicator selection

In this paper, the logistics efficiency evaluation takes the low carbon constraints into consideration, so we introduce CO₂ emissions into the input indicators based on the pollutant input method. In addition, we choose the number of logistics employees (x_1), length of logistics network (x_2) and investment in fixed asset of logistics industry (x_3) to represent the investment in manpower, material resources and financial resources of logistics industry respectively. Together with CO₂ emission (x_4), they compose the input indicators for logistics efficiency evaluation in the Beijing-Tianjin-Hebei region.

In terms of output indicators, considering the economic and social benefits, we choose gross product (y_1), cargo volume (y_2) and cargo turnover (y_3) of logistics industry as output indicators.

3.2 Data source

This paper chooses data of input and output indicators in the Beijing-Tianjin-Hebei region from 2012 to 2017, and the data is from *China Statistical Yearbook* and *China Energy Statistical Yearbook* from 2013 to 2018. In addition, there is no classification of the "logistics industry" in China's current industrial classification system, so most domestic scholars define logistics as the transportation industry, warehousing industry and postal industry. We choose the same definition in this paper, using the data from transportation, warehousing and postal industries to

replace the data of logistics industry. The data of CO₂ emissions can't be gained from the yearbook directly, so we use the calculation method published on *the IPCC national greenhouse gas listing guidelines* (2006). The fossil fuels that be considered in this paper include raw coal, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, natural gas and liquefied natural gas. By multiplying the consumption of these fossil fuels by their corresponding CO₂ emission coefficient together, we can get the data of CO₂ emissions.

The number of input and output indicators is 7 and the number of DMU is 24, so it meets the DEA empirical rule, which says that the number of DMUs should be two times more than the number of input and output indicators, proposed by Banker et al8. Then, we can do the further research.

4 Empirical analysis

This paper analyzes the efficiency of logistics industry in

Table 1. Logistics industry efficiency in the Beijing-Tianjin-Hebei region.

DMUs	TE	PTE	SE	RTS ^a
2012 Beijing	0.769	0.803	0.958	irs
2013 Beijing	0.905	1.000	0.905	drs
2014 Beijing	0.866	0.872	0.993	irs
2015 Beijing	0.91	0.927	0.981	drs
2016 Beijing	0.965	1.000	0.965	drs
2017 Beijing	1.000	1.000	1.000	-
2012 Tianjin	1.000	1.000	1.000	-
2013 Tianjin	1.000	1.000	1.000	-
2014 Tianjin	1.000	1.000	1.000	-
2015 Tianjin	0.949	0.994	0.954	irs
2016 Tianjin	0.974	0.997	0.976	irs
2017 Tianjin	1.000	1.000	1.000	-
2012 Hebei	1.000	1.000	1.000	-
2013 Hebei	1.000	1.000	1.000	-
2014 Hebei	1.000	1.000	1.000	-
2015 Hebei	0.991	1.000	0.991	irs
2016 Hebei	0.908	0.921	0.985	drs
2017 Hebei	1.000	1.000	1.000	-
2012 Beijing-Tianjin-Hebei	0.817	1.000	0.817	drs
2013 Beijing-Tianjin-Hebei	0.851	1.000	0.851	drs
2014 Beijing-Tianjin-Hebei	0.824	0.998	0.826	drs
2015 Beijing-Tianjin-Hebei	0.809	0.953	0.849	drs
2016 Beijing-Tianjin-Hebei	0.719	0.941	0.765	drs
2017 Beijing-Tianjin-Hebei	0.842	1.000	0.842	drs

^a drs: diminishing return to scale; -: constant return to scale; irs: increasing return to scale.

Table 2. Mean value of logistics industry efficiency in each region.

Region	TE	PTE	SE
Beijing	0.903	0.934	0.967
Tianjin	0.987	0.999	0.988
Hebei	0.983	0.987	0.996
Beijing-Tianjin-Hebei	0.810	0.982	0.825

4.1.1 Results analysis of logistics efficiency in the entire Beijing-Tianjin-Hebei region. From 2012 to 2017, the value of TE has improved from 0.817 to 0.842, but it

Beijing, Tianjin, Hebei and the entire region from 2012 to 2017 statically and dynamically. First of all, we use the BCC model to make a static analysis for logistics efficiency and compare the differences of these DMUs' TE, PTE and SE. Then, we use the projection analysis to explain why some DMUs are non-DEA efficiency. Finally, we use Malmquist index model to make a dynamic analysis in the six years, from which we obtain the TFPCH and its decomposition for each year and each region to make further analysis.

4.1 Static efficiency evaluation based on BCC model

According to the input and output data in Beijing, Tianjin, and Hebei province, with the help of DEAP 2.1, we obtain the results of TE, PTE and SE of logistics industry under the VRS condition. Results are showing on Tables 1 and Table 2.

never reaches the efficiency frontier in the six years. From the perspective of PTE and SE, we find that the SE of the entire region is lower than 0.9 every year; however, the PTE reaches the frontier in 2012, 2013 and 2017, and in

the other years it also exceeds 0.9. It indicates that the level of technology and management develops well in the entire Beijing-Tianjin-Hebei region, and the logistics scale and the mismatch between logistics input and output are the key factors that restrict the development of logistics industry. In terms of return to scale, the entire region has been in the diminishing stage in the past six years, which shows that this region has structural contradictions in logistics industry. Thus, it is no longer possible to promote the development of the overall logistics industry in the Beijing-Tianjin-Hebei region through expanding the scale of logistics industry.

4.1.2 Results analysis of logistics efficiency in Beijing, Tianjin and Hebei. From 2012 to 2017, the average TE of Beijing, Tianjin and Hebei are 0.903, 0.987 and 0.983 respectively, which do not reach the efficiency frontier. Tianjin has the highest average TE, and it is followed by Hebei Province and Beijing. Besides, the TE values of the three regions are better than the entire Beijing-Tianjin-Hebei region. By decomposing the comprehensive

efficiency, it shows that Tianjin’s logistics industry develops the best with the highest efficiency value in both PTE and SE. The average PTE of Tianjin reaches 0.999, which indicates that the input resources in Tianjin are close to being fully utilized. The SE of Hebei province is the best among the three regions, and it is only 0.4% away from the efficiency frontier. The efficiency of logistics industry in Beijing is in an inferior position, because the PTE and SE, which are 0.934 and 0.967 respectively, are relatively low compared with the other regions. Thus, Beijing still has broad space for the development of logistics industry.

4.2 Projection analysis of non-DEA efficient DMUs

Through the projection analysis, we further explore the input redundancy of the DMUs with non-DEA efficiency in Beijing, Tianjin and Hebei and analyze the reasons why they are inefficient. The results of input redundancy magnitude of non-DEA DMUs are shown in Table 3.

Table 3. Input redundancy magnitude of non-DEA efficient DMUs.

DMUs	Redundancy Magnitude ^b			
	x1	x2	x3	x4
2012 Beijing	0.730	0.231	0.231	0.501
2013 Beijing	0.095	0.095	0.095	0.095
2014 Beijing	0.431	0.134	0.134	0.247
2015 Beijing	0.255	0.090	0.090	0.146
2016 Beijing	0.035	0.035	0.035	0.035
2015 Tianjin	0.051	0.051	0.347	0.051
2016 Tianjin	0.026	0.033	0.287	0.462
2015 Hebei	0.009	0.009	0.009	0.009
2016 Hebei	0.092	0.092	0.092	0.092
2012 Beijing-Tianjin-Hebei	0.183	0.183	0.183	0.183
2013 Beijing-Tianjin-Hebei	0.149	0.149	0.149	0.149
2014 Beijing-Tianjin-Hebei	0.313	0.176	0.225	0.176
2015 Beijing-Tianjin-Hebei	0.308	0.191	0.191	0.191
2016 Beijing-Tianjin-Hebei	0.313	0.281	0.281	0.403
2017 Beijing-Tianjin-Hebei	0.158	0.158	0.158	0.158

^b Redundancy magnitude = $(x_{ti} - x_{ti}^*)/x_{ti}$. x_{ti} represents the i th input for DMU_t, and x_{ti}^* represents the projection value of this input⁹.

There are 15 DMUs in Table 3 in total. In 2012, the redundant magnitude of logistics employees in Beijing is 0.73 and the redundant magnitude of CO₂ emissions is 0.5. Combined with the other years, we can find that the employees and CO₂ emissions redundant are the main reasons for the low TE in Beijing. The reason for non-DEA efficiency in Tianjin is different from Beijing. In 2015, the input redundancy in Tianjin is mainly the inefficient use of fixed asset investments in logistics industry, resulting in waste of resources, while in 2016 it is the excessive CO₂ emissions. As far as the entire Beijing-Tianjin-Hebei region, the main causes of DEA ineffectiveness from 2014 to 2016 are the excessive number of logistics employees and excessive CO₂ emissions, and the length of logistics network had the minimum effect on logistics efficiency.

4.3 Dynamic efficiency evaluation based on Malmquist index

According to relevant data and using DEAP 2.1, the Malmquist index of the logistics industry and its decomposition are obtained, showing in Table 4 and Table 5.

Table 4. Logistics TFPCH and its decomposition from 2013 to 2017.

Year	EFFCH	TECHCH	PECH	SECH	TFPCH
2012-2013	0.949	1.238	1.000	0.949	1.174
2013-2014	1.054	0.677	1.000	1.054	0.714
2014-2015	1.000	0.968	1.000	1.000	0.968
2015-2016	1.000	0.949	1.000	1.000	0.949
2016-2017	0.968	1.176	1.000	0.968	1.138
Mean	0.993	0.980	1.000	0.993	0.974

Table 5. Logistics TFPCH and its decomposition in Beijing, Tianjin and Hebei.

Region	EFFCH	TECHCH	PECH	SECH	TFPCH
Beijing	1.000	1.040	1.000	1.000	1.040
Tianjin	1.000	0.887	1.000	1.000	0.887
Hebei	1.000	0.993	1.000	1.000	0.993
Beijing-Tianjin-Hebei	0.974	1.009	1.000	0.974	0.983
Mean	0.993	0.980	1.000	0.993	0.974

4.3.1 TFP analysis of logistics industry in each year.

It can be seen from Table 5 that TFPCH in the Beijing-Tianjin-Hebei region had an obvious fluctuation, which increases 17.4% and 13.8% in 2013 and 2017 and decreases 28.6%, 3.2% and 5.1% from 2014 to 2016 respectively. On average, the annual declination from 2012 to 2017 is 2.6%. From decomposition of TFPCH, it shows that the TECHCH increases in 2013 and 2017 but declines in other years with a 2% annual rate on average. The EFFCH remains unchanged in 2015 and 2016 after the fluctuation in 2013 and 2014, and then it declines again in 2017 with an average annual declination of 0.7%. Further decomposition of the EFFCH shows that the PECH of the Beijing-Tianjin-Hebei region has not changed in the six years. The SE is improved in 2014 after the declination in 2013; and then after two years of stability in 2015 and 2016, it declines again in 2017. In general, the value of SE decreases by 0.7% annually.

4.3.2 TFP analysis of logistics industry in each region.

Based on the regional differences, we further analyze the efficiency of logistics industry in Beijing, Tianjin and Hebei, and the results are shown in Table 5. From 2012 to 2017, only Beijing has an 4% increase in TFPCH, while Tianjin and Hebei have different degrees of declines, which are 11.3% and 0.7% respectively. The values of EFFCH in Beijing, Tianjin and Hebei have not changed in the six years; thus, the fluctuation of TFPCH is caused by the changes of TECHCH. From Table 5, we can see that Beijing has a slightly ascending trend in TECHCH, while Tianjin and Hebei have an obvious downward trend, which shows that their technology innovation still has a long way to develop. The value of TFPCH in the entire Beijing-Tianjin-Hebei region decreases by 1.7% per year on average. From the perspective of decomposition of TFP, we find that the TECHCH increases by 0.9% while the EFFCH decreases by 2.6%, thus, EFFCH is the significant reason for the declination of TFPCH.

5 Conclusions and Recommendations

5.1 Conclusions

5.1.1 The logistics efficiency level in the entire Beijing-Tianjin-Hebei region is relatively low, mainly affected by SE. The results show that the comprehensive efficiency of logistics industry in the entire Beijing-Tianjin-Hebei region from 2012 to 2017 is 0.810, which is significantly lower than the own efficiency value of the three regions. The TE of Tianjin and Hebei reaches 1 in every year except 2015 and 2016. Comparing with Tianjin and Hebei, Beijing's TE is lower, which has a great impact on the logistics efficiency in the entire region. From the point of view of the decomposition of TE, we find that SE is the primary reason leading to the lower TE, and it indicates that the Beijing-Tianjin-Hebei region needs to improve the resource allocation capacity and resource utilization efficiency.

5.1.2 The reason why the Beijing-Tianjin-Hebei region has lower PTE is that the logistics employees and CO₂ emissions are redundant. The results show that the input redundancy mainly focuses on the number of employees and CO₂ emissions in Beijing and on fixed asset investments and CO₂ emissions in Tianjin. In the entire region, the excessive number of logistics employees is the main reason that leads to the inefficiency in logistics industry, and the excessive CO₂ emission is the second reason.

5.1.3 The fluctuation of technology level is the main reason for the change of TFPCH in the Beijing-Tianjin-Hebei region in the past six years. From the research results in each region, we find that the EFFCH values of Beijing, Tianjin and Hebei are all equal to 1 in the six years, and the TECHCH values are 1.04, 0.887 and 0.993 respectively. Thus, TECHCH is the only reason leading to the change of TFPCH. For the entire Beijing-

Tianjin-Hebei region, the TECHCH only increases by 0.9% in the six years, which shows that it is necessary to enhance technology innovation and promote further development for the logistics industry.

5.2 Recommendations

5.2.1 Developing multimodal transport and enhancing the coordinated development in the Beijing-Tianjin-Hebei region. From the above analysis, it can be seen that the logistics comprehensive efficiency in Beijing, Tianjin and Hebei developed well, but for the entire region is not optimistic. This shows that the Beijing-Tianjin-Hebei region lacks effective coordination, and it fails to form an organic whole with complementary advantages and cooperation. Besides, there is too much redundant input, which results in unnecessary waste. The aviation logistics of Beijing, waterway logistics of Tianjin and highway transportation of Hebei are more advantageous, but they are poorly coordinated and connected¹⁰. In the future, the Beijing-Tianjin-Hebei region should organically combine these transportation modes to realize advantageous complementarities and promote common development.

5.2.2 Optimizing the structure of logistics employees and cultivating multi-level logistics talents. The advantage of Beijing in technology, culture and talent policy should be made good use of to attract high-end talents in logistics industry and to improve the level of science and technology innovation. Relatively speaking, the ability to attract high-end logistics talents in Tianjin and Hebei Province is deficient. In order to promote the technical capacity of logistics industry, Tianjin and Hebei should improve the welfare treatment for talents, so as to attract more high-end talents. At the same time, Beijing, Tianjin and Hebei should promote technology and information sharing through high-end talents joint cultivation and rational flow, as well as the construction of information sharing platform, to improve the level of science and technology and talent quality in the entire region.

5.2.3 Adjusting the energy structure and turning to low-carbon logistics. With the rapid development of economy, the demand for logistics business increases. At the same time, energy consumption and CO₂ emission of logistics industry also increase with the scale expansion of logistics industry. This problem is mainly due to the insufficient investment in clean technology and equipment of logistics operations and the backward development of circular logistics and reverse logistics¹¹. Therefore, China should make effort to develop the technology of low-carbon energy and technology of energy-saving and emission-reducing, to update the logistics equipment with high energy consumption, to promote the use of new trucks with low fuel consumption, and finally, to create a good environment for low-carbon logistics.

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