Research on Efficiency Evaluation of Fresh Food Cold Chain Logistics in Central China

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Abstract

As an agricultural region in Central China, there are many kinds of fresh food and abundant resources, but the development of fresh food cold chain logistics lags behind and cannot meet the current market demand. Efficiency evaluation is the direction to promote the continuous improvement of fresh food cold chain logistics. Therefore, by evaluating the efficiency of fresh cold chain logistics and analyzing the factors affecting the efficiency, it can provide theoretical basis for the subsequent planning and development of fresh cold chain logistics.

Based on this, this research analyzed the relationship between supply and demand of fresh food and the development status of fresh food cold chain logistics. Then, base on DEA-Malmquist, this research measured the efficiency of fresh cold chain logistics in Central China from 2016 to 2019. Finally, according to the results of efficiency evaluation and the analysis of factors affecting efficiency, this research put forward relevant suggestions to improve the efficiency of fresh food cold chain logistics in central China.

1. Introduction

In recent years, China's economy has shifted from a high-speed growth stage to a high-quality development stage. However, China's cold chain logistics industry started late, its technology is immature and its application scope is small, which leads to the rot rate of fresh products in the process of cold chain transportation in China being much higher than that in western developed countries.

Central China (Henan, Hubei and Hunan Provinces) has an advantage in geographical location. There are air cargo, land and water transportation in the continuous development. These three provinces are traditional agricultural provinces, rich in agricultural, aquatic and livestock products.Therefore, the input and output efficiency of fresh cold chain logistics in Central China are studied. They have a high demand for cold chain logistics, but still face problems such as asymmetry in cold chain development, lack of professionals and uneven logistics resources.

1. Introduction

DEA does not require pre-estimation parameters and is able to direct calculate the data; therefore, as it has been found to be superior in solving more complicated multi-input and multi-output efficiency evaluations (Wei, 2006), it has been widely used for logistics efficiency evaluations. Many scholars evaluate logistics efficiency from various perspectives, such as the evaluation of logistics efficiency between countries (Markovits-Somogyi and Zoltan, 2014), the evaluation of port logistics efficiency (Schoyen et al., 2018), sustainability of logistics efficiency (Rashidi and Kevin, 2019), carbon emission performance of the transportation industry (Zhou et al., 2013).

DEA-BCC can only evaluate the efficiency of multiple subjects in one period or multiple periods of one subject. Malmquist model can be used for dynamic evaluation which is multi-subject and multi-period efficiency measurement.

Taking the fresh cold chain logistics in three provinces (Henan, Hunan and Hubei) of central China as the research object, according to the real data, the efficiency of fresh cold chain logistics in central China is comprehensively evaluated by using DEA-Malmquist model.

2. literature review

Author	Details
Yu Yong, Zhang Chen (2008)	On the basis of cold chain logistics at home and abroad, they analyzed these problems for some specific foreign practices and further put forward reasonable solutions suitable for China's national conditions to solve these problems.
Amir Shabani and Seyed Mohammad Reza Torabipour, Reza Farzipoor Saen (2011)	introduced an innovative data envelopment analysis (**DEA**) model entitled "Non-binary Arithmetic Operator Dual-role" (**NAOD**) under free disposability assumption for selecting the refrigerated containers in cold chain management (CCM).
Zhao Liang, Ma Qiuyan (2015)	with the fresh farm produce cold chain logistics system of Henan TOPIN Group from 2011 to 2013 as the object, then used **DEA** to analyze the validity of the cold chain logistics system and put forward suggestions for improvement.
Xu Weishu, Yu Xiangyu (2015)	Used **DEA** to analyze the agricultural producecold chain logistics data of the 11 cities in Shanxi, and then gave the corresponding suggestions for improvement.
Zhang Xu, Zhang Wenfeng (2017)	Used the **DEA** method and the panel data to evaluate the efficiency of cold chain logistics of fresh agricultural products in Guangzhou for 3 years and put forward relevant suggestions.
You Xiaoling, Hong Guobin (2017)	constructed the storage transport network, and then establishing three kinds of organization structure mode which considering the cold chain logistics market to analysis **two-stage DEA**.
Antonio Carlos Rodrigues, Ricardo Silveira Martins, Peter Fernandes Wanke,Janaina Siegler (2018)	used **DEA** and robust regression approach in secondary data to determine the variables that significantly affect the efficiency of third-party logistics (3PL) providers of refrigeration services and propose ways to improve the competitiveness of specialized 3PLs.
Yang Weiqiong, Tai Xiaojia (2021)	used the factor analysis method to reduce the relevant panel data, then performed the evaluation of the dynamic and static efficiency of agricultural products circulation system by using the **DEA-Malmquist** index analysis method.

2. literature review

Author	Input index	Output index
Xu Weishu, Yu Xiangyu (2015)	Special truck transportation rate, fixed asset investment rate, the government's policy on agricultural products	The economic contribution of agricultural products logistics, fruit output per unit of GDP, and elasticity of logistics growth
Zhao Liang, Ma Qiuyan (2015)	The number of logistics employees, information technology and other fixed asset investment, refrigeration, the total number of freezers, cold chain logistics transportation costs, government investment	Freight volume of fresh agricultural products, total turnover of fresh agricultural products, total profits
Li Jinfeng (2016)	Special truck transportation rate, fixed asset investment rate, agricultural product policy strength	The economic contribution of agricultural products logistics, fruit output per unit of GDP, and elasticity of logistics growth
Zhang xu (2017)	The number of logistics Employees, information technology and other fixed asset investment, the total number of cold storage, transportation costs	Freight volume of fresh agricultural products, total turnover of fresh agricultural products, total profits

3.Methodology

- A. Static efficiency analysis:

Using the DEA-BCC model can obtain technical Efficiency (TE) and pure Technical Efficiency (PTE), and scale efficiency (SE) can be obtained by using relational SE=TE/PTE. The study also carries out vertical comparison analysis on time dimension (2016-2019) and horizontal comparison analysis with other regions.

- B. Dynamic efficiency analysis:

Malmquist index is used to get the efficiency change , technical change and productivity change for each time period and each DMU.

3.Methodology

DEA-BBC:

$$\min \left[\theta - \varepsilon\left(e_1^T S^- + e_2^T S^+\right)\right]$$

$$\text{s.t.} \quad \begin{aligned} &\sum_{j=1}^{n} X_j \lambda_j + S^- = \theta X_0 \\ &\sum_{j=1}^{n} Y_j \lambda_j - S^+ = Y_0 \\ &\sum_{j=1}^{n} \lambda_j = 1 \\ &\lambda_j \geq 0, S^- \geq 0, S^+ \geq 0, j = 1,2,\ldots,n \end{aligned}$$

For the *j-th* DMU_i (i = 1, 2, …, n), m input index constitute the input vector X_j and the weight vector of the input index is v_j ; n output index constitute the output vector Y_j and the weight vector of the output index is u_j .

$\theta < 1$: indicates that the technology of the DMU is invalid. At this time, the DMU has the problem that the input resources can not be fully converted into output or the input resources are excessive

$\theta = 1$: indicates that the DMU is in a technically effective state.

3.Methodology

Technical efficiency (crste)

- crste=1: The technical efficiency is effective. The resource allocation is reasonable and the input and output are in the best condition.
- 0.9<crste<1: The resource allocation is slightly unreasonable, and the input and output are not in the best condition, so the comprehensive efficiency is weak and effective.
- 0<crste<0.9: The allocation of resources is obviously unreasonable, and there is a big gap between input and output and the best situation, at which time the comprehensive efficiency is invalid.

Pure technical efficiency (vrste)

- vrste=1: The use of input resources is effective at the current technical level.
- vrste<1: The use of input resources is not effective under the current technical level, which means that the technical level cannot meet the needs of industrial development at this time.

Scale efficiency (scale)

- scale=1: The production scale reaches the optimal state under the current conditions.
- scale<1: The production scale and efficiency are not suitable, and the scale is invalid at this time.

3.Methodology

Malmquist index:

Assuming a single input (x) and output (y) in (t,t+1) period, the total factor productivity is: $TFP = \frac{y^{t+1}x^t}{x^{t+1}y^t}$. D^t is the distance function between each DMU.

$$TFPch = M(x^{t+1}, y^{t+1}, x^t, y^t)$$
$$= [\frac{D^{t+1}(x^{t+1}y^{t+1})}{D^t(x^t y^t)} * \frac{D^t(x^{t+1}y^{t+1})}{D^t(x^t y^t)}]^{1/2}$$
$$TFPch = EFFch \times TEch = PEch \times SEch \times TEch$$

TFPch: total factor productivity change; EFFch: technical efficiency change; TEch: technological change

PEch: pure technical efficiency change; SEch: scale efficiency change

- TFPch>1 : the level of total factor productivity is improving, the cold chain logistics industry of fresh agricultural products in this province is on the rise in technology and scale, and the allocation of resources is reasonable.
- TFPch<1 : TFP level shows a dynamic change of decline in this stage.

4. Data

	index	Variables	Unit
Input	Fresh cold chain logistics fixed asset investment	X1	billion yuan
	Number of employees related to logistics	X2	10,000 people
	Cold storage capacity	X3	10,000 tons
Output	Fresh cold chain freight volume	Y1	10,000 tons
	Fresh cold chain logistics industry value added	Y2	billion yuan

- **Data collection level:** Data on index for 30 provinces (as DMUs) in China
- **Research period:** 2016-2019
- **Sources of data:**

  (2017-2020)

  China Statistical Yearbook, China Cold Chain Logistics Development Report, China Logistics Yearbook and Provincial Statistical Yearbooks and other related databases.
- **Data processing tool:** DEAP 2.1 software

5. Results and analysis

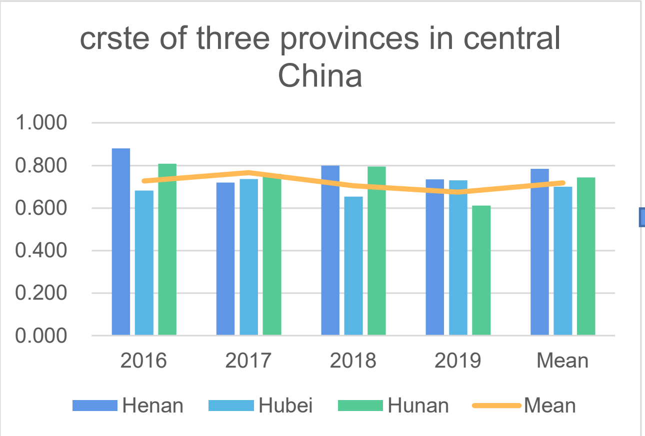
5.1 Technical efficiency

- crste (the three provinces in 4 years) < 0.9

  →Technical efficiency is ineffective.

  →The allocation of cold chain logistics resources in central China in the past four years is not reasonable

  ← The large difference in fixed asset investment in these provinces each year or the late construction of large cold storage.



- mean crste (Hubei) < 0.718

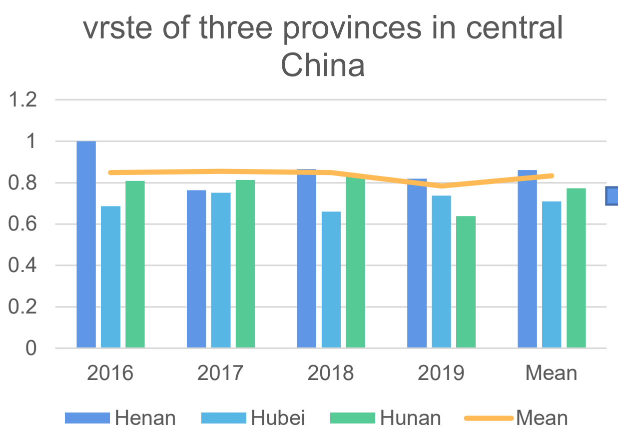
  → At a low level of development.
- mean crste (Henan, Hunan)> 0.718 , but the TE has decreased from 2018 to 2019.

Technical efficiency values for each DMU for 2016-2019

DMU	2016	2017	2018	2019	Mean
Beijing	0.632	0.531	0.452	0.375	0.498
Tianjin	0.642	0.713	0.711	0.491	0.639
Hebei	1.000	1.000	1.000	0.996	0.999
Shanxi	0.597	1.000	0.985	0.859	0.860
Neimenggu	1.000	1.000	1.000	1.000	1.000
Liaoning	1.000	1.000	1.000	1.000	1.000
Jilin	0.775	1.000	0.598	0.592	0.741
Heilongjiang	0.876	1.000	1.000	0.888	0.941
Shanghai	0.722	0.666	0.571	0.511	0.618
Jiangsu	0.768	0.737	0.838	0.674	0.754
Zhejiang	0.642	0.576	0.562	0.463	0.561
Anhui	1.000	1.000	0.683	0.751	0.859
Fujian	1.000	0.964	1.000	1.000	0.991
Jiangxi	0.910	1.000	0.822	0.788	0.880
Shandong	0.954	0.882	0.909	0.915	0.915
Henan	0.881	0.720	0.799	0.735	0.784
Hubei	0.682	0.736	0.653	0.730	0.700
Hunan	0.808	0.761	0.795	0.612	0.744
Guangdong	0.689	0.589	0.599	0.567	0.611
Guangxi	0.745	1.000	0.770	0.606	0.780
Hainan	0.933	0.845	0.801	1.000	0.895
Chongqing	0.332	0.294	0.294	0.283	0.301
Sichuan	0.474	0.608	0.621	0.436	0.535
Guizhou	0.411	0.485	0.441	0.425	0.441
Yunnan	0.613	0.775	0.711	0.872	0.743
Shanxi	0.528	0.462	0.311	0.313	0.404
Gansu	0.307	0.434	0.301	0.299	0.335
Qinghai	0.383	0.545	0.332	0.396	0.414
Ningxia	1.000	1.000	1.000	1.000	1.000
Xinjiang	0.547	0.648	0.556	0.674	0.606
Mean	0.728	0.766	0.704	0.675	0.718

5. Results and analysis

5.2 Pure technical efficiency



- mean vrste (Hubei, Hunan, each year) < mean vrste (each year)
  → Their overall technical level can not support the development of cold chain logistics.
  → In a great waste of resources.
- PTE fluctuates, mainly due to different annual technology inputs.

- Cold chain logistics in the technical level and management level, management concept training and in-depth is far from enough.

Pure technical efficiency values for each DMU for 2016-2019					
DMU	2016	2017	2018	2019	Mean
Beijing	0.800	0.595	0.578	0.488	0.615
Tianjin	0.891	1.000	1.000	0.789	0.920
Hebei	1.000	1.000	1.000	1.000	1.000
Shanxi	1.000	1.000	1.000	1.000	1.000
Neimenggu	1.000	1.000	1.000	1.000	1.000
Liaoning	1.000	1.000	1.000	1.000	1.000
Jilin	0.884	1.000	1.000	0.676	0.890
Heilongjiang	0.882	1.000	1.000	1.000	0.971
Shanghai	1.000	0.672	0.674	1.000	0.837
Jiangsu	0.844	0.792	1.000	0.774	0.853
Zhejiang	0.642	0.576	0.572	0.495	0.571
Anhui	1.000	1.000	0.781	0.759	0.885
Fujian	1.000	1.000	1.000	1.000	1.000
Jiangxi	1.000	1.000	0.892	0.794	0.922
Shandong	1.000	1.000	1.000	1.000	1.000
Henan	1.000	0.764	0.866	0.819	0.862
Hubei	0.687	0.751	0.661	0.738	0.709
Hunan	0.809	0.813	0.831	0.638	0.773
Guangdong	0.869	0.830	0.916	1.000	0.904
Guangxi	0.762	1.000	0.787	0.668	0.804
Hainan	1.000	0.962	1.000	1.000	0.991
Chongqing	0.562	0.461	0.558	0.326	0.477
Sichuan	0.478	0.609	0.621	0.436	0.536
Guizhou	0.619	0.604	0.728	0.580	0.633
Yunnan	0.617	0.808	0.720	0.901	0.762
Shanxi	0.823	0.702	0.709	0.409	0.661
Gansu	0.616	0.995	0.818	0.491	0.730
Qinghai	1.000	1.000	1.000	1.000	1.000
Ningxia	1.000	1.000	1.000	1.000	1.000
Xinjiang	0.672	0.720	0.753	0.748	0.723
Mean	0.849	0.855	0.849	0.784	0.834

5. Results and analysis

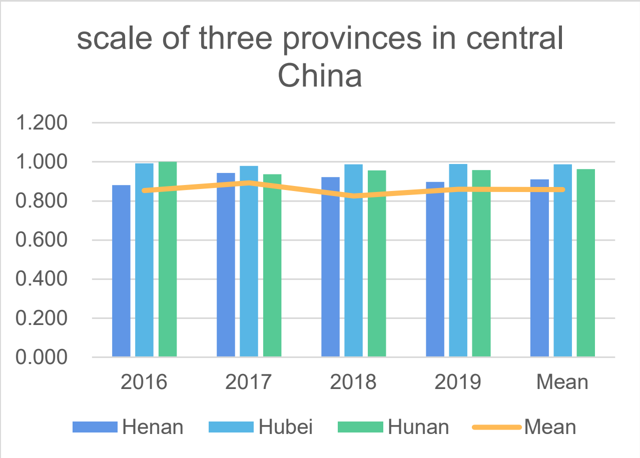
5.3 Scale efficiency

Scale remuneration of 3 provinces for 2016-2019				
	2016	2017	2018	2019
Henan	drs	drs	drs	drs
Hubei	drs	drs	drs	drs
Hunan	—	drs	drs	drs

- Decreasing return to scale

  → These provinces attach more importance to industrial scale than to the input of technical and human resources,

  →leads to unlimited expansion of scale without planning.



- mean scale (3 provinces each year) > mean scale (30 provinces each year)

  → At a relatively high level.
- Scale efficiency each year is very close to 1,

  → As long as the cold chain logistics scale of a small adjustment can be achieved effectively.

scale efficiency values for each DMU for 2016-2019					
DMU	2016	2017	2018	2019	Mean
Beijing	0.790	0.892	0.782	0.769	0.808
Tianjin	0.720	0.713	0.711	0.622	0.692
Hebei	1.000	1.000	1.000	0.996	0.999
Shanxi	0.597	1.000	0.985	0.859	0.860
Neimenggu	1.000	1.000	1.000	1.000	1.000
Liaoning	1.000	1.000	1.000	1.000	1.000
Jilin	0.877	1.000	0.598	0.875	0.838
Heilongjiang	0.993	1.000	1.000	0.888	0.970
Shanghai	0.722	0.991	0.848	0.511	0.768
Jiangsu	0.910	0.930	0.838	0.871	0.887
Zhejiang	1.000	0.999	0.983	0.935	0.979
Anhui	1.000	1.000	0.875	0.989	0.966
Fujian	1.000	0.964	1.000	1.000	0.991
Jiangxi	0.910	1.000	0.921	0.992	0.956
Shandong	0.954	0.882	0.909	0.915	0.915
Henan	0.881	0.943	0.923	0.898	0.911
Hubei	0.992	0.980	0.988	0.990	0.988
Hunan	1.000	0.937	0.957	0.959	0.963
Guangdong	0.793	0.709	0.654	0.567	0.681
Guangxi	0.977	1.000	0.978	0.907	0.966
Hainan	0.933	0.878	0.801	1.000	0.903
Chongqing	0.591	0.638	0.527	0.869	0.656
Sichuan	0.992	0.998	0.999	1.000	0.997
Guizhou	0.664	0.802	0.606	0.733	0.701
Yunnan	0.993	0.959	0.988	0.969	0.977
Shanxi	0.642	0.657	0.439	0.766	0.626
Gansu	0.499	0.436	0.367	0.609	0.478
Qinghai	0.383	0.545	0.332	0.396	0.414
Ningxia	1.000	1.000	1.000	1.000	1.000
Xinjiang	0.815	0.900	0.738	0.902	0.839
Mean	0.854	0.892	0.825	0.860	0.858

5. Results and analysis

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5.4 Input and Output Slacks

Henan					
	output slacks		input slacks		
Year	S1+	S2+	S1-	S2-	S3-
2016	0	0	0	0	0
2017	44.908	0	0	7.697	52.914
2018	188.099	0	0	0	0
2019	143.069	0	0	5.815	147.594

In 2016, there was no input redundancy and insufficient output, but in other years, there were input redundancy and insufficient output to varying degrees.

Hubei					
	output slacks		input slacks		
Year	S1+	S2+	S1-	S2-	S3-
2016	0	0	0	0	24.492
2017	0	0	77.809	2.216	0
2018	0	0	0	0	15.642
2019	6.42	0	0	0	110.386

In each year, input redundancy and output insufficiency occur to varying degrees.

Hunan					
	output slacks		input slacks		
Year	S1+	S2+	S1-	S2-	S3-
2016	0	0	0	0	71.956
2017	0	0	0	0	51.808
2018	0	0	0	0	44.395
2019	0	0	0	0	123.292

Every year, there is no shortage of output, but there is redundancy of cold storage input.

There is input redundancy when there is insufficient output. → Resource allocation is not reasonable enough.

The quantity and proportion of fixed asset investment, employment about cold chain and cold storage construction should be adjusted to increase output.

5. Results and analysis

5.5 Malmquist index

DMU	effch	techch	pech	sech	tfpch
Henan	0.941	1.012	0.936	1.006	0.953
Hubei	1.023	0.948	1.024	0.999	0.970
Hunan	0.912	1.047	0.924	0.986	0.955
Mean	0.959	1.002	0.961	0.997	0.959

- tfpch (all three provinces) < 1 → A downward trend
- There are decreases in technical efficiency, pure technical efficiency, scale efficiency or technical level. Among them, especially the pure technical efficiency and scale efficiency decrease more.

→ The central Region of China has less investment in technological innovation and industrial scale expansion, which in turn leads to a decline in total factor productivity.

6. Conclusion

This research used DEA and Mamlquist index analysis to study the logistics efficiency of fresh food cold chain in central China in 2016-2019, and concluded the following conclusions:

1. The logistics efficiency level of fresh food in central China is general, and there is a lot of room for progress. In 4 years, the technical efficiency of the three provinces has not reached 1, the allocation of input resources is unreasonable, and the resources have not been fully utilized.
2. Input redundancy and output shortage are common in Central China. Because the scale returns in Central China are decreasing, the output will increase in a higher proportion after the input is reduced. Therefore, we can make full use of resources by adjusting the structure and proportion of resource input.
3. From effch=pech*sech, mean(pech)=0.961<mean (sech)=0.997, the main reason for the decline in technological efficiency in central China is the decline in pure technology efficiency. It shows the overall central China in the fresh food cold chain logistics technology investment is lower than the industrial scale input, the existing technology can not support the development of industrial scale. In the future should pay more attention to the innovation of related technologies and equipment innovation, in order to achieve the optimal allocation of resources.

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Thank you!