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FINANCIAL EFFICIENCY AND FINANCIAL RESOURCE ALLOCATION OF BEIJING–TIANJIN–HEBEI URBAN AGGLOMERATION

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Abstract. This study focuses on improving financial efficiency and rationally allocating financial resources in the Beijing–Tianjin–Hebei, based on data from 2011 to 2019. Firstly, the Slack-Based Measure (SBM) model based on Shannon Entropy is adopted to measure financial efficiency in Beijing–Tianjin–Hebei. Secondly, a Beijing–Tianjin–Hebei inter-regional financial resource allocation scheme is proposed using the Generalized Equilibrium Efficient Frontier Data Envelopment Analysis (GEEFDEA) model. Finally, the external environmental factors influencing financial efficiency are explored using spatial and other econometric models. Efficiency measurement reveals that financial efficiency in Beijing–Tianjin–Hebei is unevenly developed. The financial efficiency of Beijing, Tianjin, and Zhangjiakou is high and stable, whereas the financial efficiency of Tangshan, Langfang, and Shijiazhuang is high, but fluctuates significantly. In comparison, the financial efficiency of other cities is low. The factors and the adjustment amount to improve urban financial efficiency are obtained by studying the allocation of financial resources. And it is found that Tianjin and Tangshan have more financial resource surpluses than other cities. By exploring influencing factors, it is found that the financial development level, innovation level, and infrastructure construction level of Beijing–Tianjin–Hebei significantly affect financial efficiency.

Mathematics Subject Classification. 90C05.

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1. Introduction

From a regional perspective, financial efficiency refers to the level of financial development and the allocation of financial resources in the region's financial system [43]. China's financial resources have grown rapidly since its reform and opening up over 40 years ago. However, due to the lagging implementation of financial development strategy reform, China has not been able to meet the requirements of economic development for effective financial resource allocation. In emphasizing the subordination and support of financial policies to economic growth and monetary stability, China has neglected the fundamental role of financial efficiency in fostering economic expansion and guaranteeing financial stability [17]. Financial resources are a unique, limited, and

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scarce commodity. To ensure regional socio-economic development, the allocation of inter-regional financial resources must be clearly understood. This includes a thorough understanding of the supply and demand of financial resources in each region. Only then can financial development be effectively regulated. Establishing central financial efficiency objectives for financial management system reform and macro-financial policy can more effectively serve the needs of economic development and financial stability [10].

The Beijing–Tianjin–Hebei economic capital circle plays a significant role in regional economic development for China. The coordination of the Beijing–Tianjin–Hebei region is part of China's national strategy and has become a key economic priority for the country's future construction. To strengthen overall competitiveness and optimize the allocation of resources, the Beijing–Tianjin–Hebei urban agglomeration has been consistently exploring new approaches to support the integration of financial and economic resources. In particular, the financial industry of Beijing–Tianjin–Hebei has seen a significant increase since the introduction of the "Beijing–Tianjin–Hebei Cooperative Development Strategy". However, many issues remain. Among them, the imbalance in the quantity and distribution of financial resources between regions is particularly salient. There are many idle resources in some regions, while financial resources are scarce in other regions, leading to the ineffective circulation of resources between these regions.

Efficiency is the core consideration when allocating resources. This article will first adopt the SBM model based on Shannon entropy to evaluate the financial efficiency in the Beijing–Tianjin–Hebei region. Incorporating Shannon entropy into the SBM model can significantly enhance its discriminative capability. Additionally, financial development has competition and resource allocation issues across different regions. Resource integration optimization is an effective means to support the collaborative advancement of the Beijing–Tianjin–Hebei region. Therefore, the GEEFDEA model will be utilized to consider the limited availability of resources and to derive precise financial resource allocation between the regions from the perspective of fixed-sum output. Finally, truncated regression, panel Tobit, and spatial econometric models will be employed to explore the external environmental factors that influence financial efficiency, aiming to improve the environmental guarantee for enhancing financial efficiency.

2. Literature review

The literature on financial efficiency and financial resource allocation can be divided into three aspects: (1) the influencing factors of financial efficiency, (2) the evaluation methods of financial efficiency, and (3) resource allocation models from the perspective of efficiency.

2.1. The influencing factors of financial efficiency

While numerous factors influence financial efficiency, most studies have focused on macroeconomic growth, financial development, and scientific development. Regarding macroeconomics, Blejer [1] found that advanced financial systems had faster economic growth than countries with less financial efficiency. Lozano-Vivas and Pastor [22] explored the dynamic evolution of macroeconomic and financial efficiency, concluding that their evolution trends were similar. According to Mohamad *et al.* [27], regulatory efficiency and market openness positively affected financial efficiency. Regarding financial development, Le *et al.* [14] explored the impact of inclusive finance on financial efficiency. They determined that financial inclusion had a negative impact on the improvement of financial efficiency. Fernandes *et al.* [6] observed that reduced financial development levels led to financial efficiency being vulnerable to risk and volatility. Joshua [12] found that bank mergers and acquisitions could improve financial efficiency. In terms of scientific development, Wu *et al.* [42] suggested that advances in financial technology had a U-shaped effect on financial efficiency.

2.2. Financial efficiency evaluation methods

There are numerous domestic and international studies on "financial efficiency evaluation" in Table 1. Among them, the data envelopment analysis (DEA) model is commonly adopted to measure financial efficiency [36,37]. Many scholars have subsequently improved and innovated the traditional DEA models [33,35]. For example, Hu

TABLE 1. Studies on "financial efficiency evaluation".

Evaluation methodologies	Authors
DEA series methods	Cui and Wang [5] Kamel *et al.* [13] Chang *et al.* [3] Iqbal *et al.* [11]
Measurement of indicators	Wu *et al.* [42] Xu and Ullah [47]
PCA	Le *et al.* [14]

et al. [9] applied the DEA-BCC model and the DEA-Malmquist index to discern pairwise static and dynamic measures of provincial financial efficiency in China. In actual practice, not all inputs and outputs change proportionally. To make up for the deficiencies of the radial models (CCR and BCC), Tone [38] introduced the SBM model, which has the advantage of considering the input and output slack variables separately, thereby introducing the objective function. To counteract the impact of undesirable output on efficiency assessment, Tone [39] refined the SBM model by proposing an SBM model with undesirable output. Liu *et al.* [21] measured eco-efficiency influenced by green financial development using the super-efficient SBM model. Xie *et al.* [44] incorporated Shannon entropy into a DEA model, thus improving its identification capabilities. Moreover, Ma *et al.* [25] and Xie *et al.* [45] incorporated Shannon entropy into the undesirable output SBM efficiency evaluation system to measure the financial efficiency of Chinese provinces.

2.3. The resource allocation model from an efficiency perspective

The effective allocation of financial resources directly affects the service efficiency of resources and the benefits of the real economy [16, 18]. Liao *et al.* [19] discovered that regional financial resource allocation efficiency has evident spatial agglomeration and spillover effects. Ni *et al.* [28] characterized the efficiency, effective allocation, and improper manufacturing factor allocation within and between cities. Wan [40] constructed a multi-objective model to optimize the allocation of financial resources in different regions.

The essence of improving capital allocation efficiency resides in the flow of capital from low-efficiency regions (industries) to high-efficiency regions (industries). Decision-Making Units (DMUs) often compete with one another for limited resources [31, 46]. To accommodate the finite output among DMUs, Lins *et al.* [20] proposed the Zero-Sum Game Data Envelopment Analysis (ZSGDEA) model to evaluate the resource allocation performance of each DMU, assuming the sum of outputs remains constant. The ZSGDEA model has also been modified to consider undesirable outputs [7]. By extending the ZSGDEA model from one-dimensional to multidimensional, Yang *et al.* [48] created the Fixed-Sum Outputs Data Envelopment Analysis (FSODEA) model. The FSODEA model evaluates each DMU based on different effective frontiers, resulting in less objective results. To address the existing problem, Yang *et al.* [49] proposed the EEFDEA model to evaluate decision-making units with fixed-sum outputs on a public platform. Subsequently, Yang *et al.* [50] improved upon this model through the GEEFDEA method.

Based on the previous literature on financial efficiency, numerous studies exist on financial efficiency and resource allocation. However, previous research has mainly focused on exploring the influencing factors of financial efficiency and resource allocation. Fewer studies have investigated concrete pathways to improve financial efficiency and optimize financial resource allocation. The contributions of this article are as follows. Firstly, it measures the financial efficiency of the Beijing–Tianjin–Hebei urban agglomeration using the SBM model based on Shannon entropy. Including Shannon entropy in the SBM model can significantly improve the identification ability. Secondly, it proposes a specific path for adjusting financial resources among regions in the Beijing–Tianjin–Hebei area using the fixed-sum outputs GEEFDEA model, achieving both financial efficiency

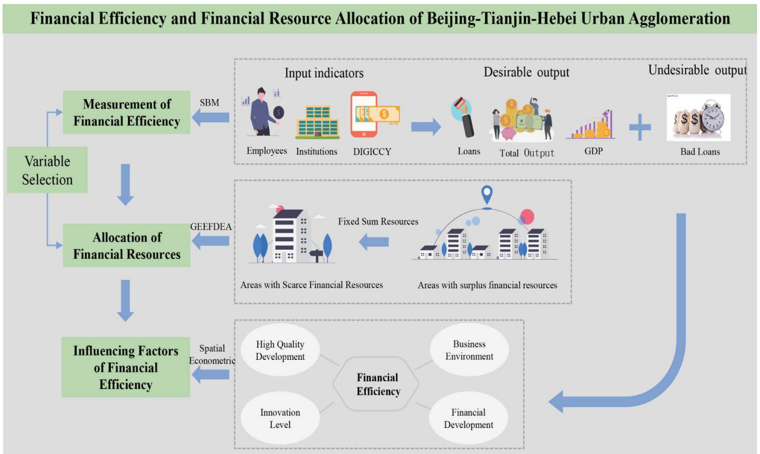


Figure 1. Technology roadmap.

and effective allocation of financial resources. Furthermore, this article reveals the environmental factors that influence the financial efficiency of the Beijing–Tianjin–Hebei region, providing solid external support for efficiency enhancement.

3. Methodology

The following approach is employed to analyze the financial efficiency and financial resource allocation problems of the Beijing–Tianjin–Hebei metropolitan region. The technology roadmap is presented in Figure 1.

3.1. Variable selection model

In the practical application of DEA models, decision-makers may encounter information redundancy in the dataset due to the high number of input and output variables. To enhance the effectiveness of selecting input-output indicators for measuring efficiency, this study employs three classic selection methods, namely AIC, BIC, and HQC, to screen the indicators. Firstly, Li *et al.* [16] proposed a way to screen out the appropriate variables based on AIC:

$$\theta_j = \sum_{r\in Q} \beta_r Y_{rj} - \sum_{i\in P} a_i X_{ij} + \varepsilon_j, j \in N$$
$$a_i, \beta_r \geq 0, \qquad \forall i \in P, r \in Q \tag{1}$$

where P and Q are subsets of the input and output variables in the indicator system, $P \subset M, Q \subset S$; a_i and β_r are the multipliers connected with the i-th input and r-th output, respectively. The estimated value of AIC is obtained in accordance with the theory of maximum likelihood estimation:

$$\mathrm{AIC}(P,Q) = -3\ln[\mathrm{MLE}(P,Q)] + 2(|P| + |Q|). \tag{2}$$

where $\mathrm{MLE}(P,Q)$ is the natural logarithm transformation, and $|P|$ and $|Q|$ are the number of variables. In fact, $|P| + |Q|$ is the penalty term in the selection of AIC variables. The identification ability of the model is reduced as more variables are selected, while a smaller AIC value results in less redundant information in the model, making it more accurate.

Subsequently, the BIC and HQC are successively employed. Among them, BIC compensates for the deficiency of AIC [30], while HQC is another model selection criterion used in statistical computing [8].

3.2. The SBM model based on Shannon entropy

In this study, the SBM model based on Shannon entropy is used to measure financial efficiency. The inclusion of Shannon entropy can significantly enhance the discriminative ability of the DEA model, thus making the DEA methodology with Shannon entropy outperform traditional data envelopment analysis in all cases. Additionally, the SBM model considers the impact of undesirable outputs on efficiency. Due to the presence of non-performing loans, it is necessary to consider undesirable outputs when measuring the financial efficiency in the Beijing–Tianjin–Hebei region. First, the SBM model constructed by Tone [39] is applied. Suppose there are n independent DMUs and each DMU has m kinds of inputs, S_1 kinds of desirable outputs, and S_2 kinds of undesirable outputs, which are represented by three vectors $x \in R^m$, $y^g \in R^{s_1}$, and $y^b \in R^{s_2}$, respectively. Assuming $X > 0, Y^g > 0, Y^b > 0$, the production possible set (P) is defined as:

$$P = \left\{\left(X, Y^g, Y^b\right) \mid x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\right\}. \tag{3}$$

Modelling is as follows:

$$\begin{aligned} \rho^* = \text{Min}\ & \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_T^g}{y_{ro}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)} \\ \text{s.t.}\ & x_o = X\lambda + s^- \\ & y_o^g = Y^g\lambda - s^g \\ & y_o^b = Y^b\lambda + s^b \\ & s^-, s^g, s^b \geq 0, \lambda \geq 0. \end{aligned} \tag{4}$$

Referring to Xie *et al.* [44,45], and Ma *et al.* [25], the SBM model of undesirable output is fused with Shannon entropy to obtain the comprehensive efficiency score, enhancing the discriminatory power of the traditional DEA model. Suppose there are $M = \{1, 2, \cdots, m\}$ inputs and $S = \{1, 2, \cdots, s\}$ outputs, and the number of combinations is $K = (2^m - 1) \times (2^s - 1)$. Based on the SBM model, the k-th combination of the variable set M_K is calculated. The model set is $\Omega = \{M_1, \cdots, M_K\}$, and $E_{jk}(j = 1, \cdots, n, k = 1, \cdots, K)$ denotes the efficiency that is calculated based on M_K. By calculating k times with the model, the efficiency matrix $[E_{jk}]_{n\times K}$ is obtained as:

$$\begin{array}{c} \\ \text{DMU}_1 \\ \text{DMU}_2 \\ \vdots \\ \text{DMU}_n \end{array} \begin{array}{c} \begin{array}{cccc} M_1 & M_2 & \cdots & M_K \end{array} \\ \begin{bmatrix} E_{11} & E_{12} & \cdots & E_{1k} \\ E_{21} & E_{22} & \cdots & E_{2k} \\ \vdots & \vdots & \cdots & \vdots \\ E_{n1} & E_{n2} & \cdots & E_{nk} \end{bmatrix} \end{array}. \tag{5}$$

Then, standardize the efficiency matrix $[E_{jk}]_{n\times K}$ and specify $e_{jk} = E_{jk}/\sum_{j=1}^{n} E_{jk}, k = 1, 2, \ldots, K$. Calculate the Shannon entropy, $f_k = -(\ln n)^{-1}\sum_{j=1}^{n} e_{jk}\ln(e_{jk}), k = 1, 2, \ldots, K$. Finally, comprehensive efficiency score (CES) is obtained by empowering the combination efficiency.

If comprehensive efficiency score (CES) = 1, the comprehensive DEA is determined to be effective; if not, it is judged to be invalid. The comprehensive efficiency score is only valid if the DMU is valid in all variable combinations. Consequently, incorporating this score into Shannon entropy can significantly improve the identification ability of the DEA model, enabling the performance of the Shannon entropy DEA method to outperform traditional data envelopment analysis in all cases.

3.3. The fixed-sum outputs GEEFDEA model

To achieve the optimal allocation of fixed-sum financial resources in the most efficient manner, we employ the GEEFDEA model to calculate the adjustment amount. Referring to the models of Yang *et al.* [50] and Ma *et al.* [24], suppose inputs $x_{ij}(i=1,\ldots,m;j=1,\ldots n)$ and variable-sum outputs $y_{rj}(r=1,\ldots s)$ and fixed-sum outputs $f_{tj}(t=1,\ldots,l)$. While the fixed-sum outputs must satisfy the constraint $\sum_{j=1}^{n} f_{tj} = F_t(t=1,\ldots,l)$. The models are provided as follows:

$$\begin{aligned}
\text{Min} \; & \sum_{j=1}^{n}\sum_{t=1}^{l} w_t\alpha_{tj} \\
\text{s.t.} \; & \frac{\sum_{r=1}^{s} u_r y_{rj} + \sum_{t=1}^{l} w_t(f_{tj}+\delta_{tj}) + \mu_0}{\sum_{i=1}^{m} v_i x_{ij}} = 1, && \forall i,r,t,j \\
& \sum_{j=1}^{n} \delta_{tj} = 0, && \forall t \\
& \alpha_{tj} = \max\{\delta_{tj}, 0\}, && \forall t,j \\
& f_{tj} + \delta_{tj} \geq 0, && \forall t,j \\
& u_r, v_i, w_t \geq 0, \delta_{tj}, \mu_0 \text{ are free}
\end{aligned} \tag{6}$$

where u_r, w_t, v_i are the weights of the variable-sum outputs y_{rj}, fixed-sum outputs f_{tj}, and input variables x_{ij}, respectively. Additionally, δ_{tj} is the adjustment amount of the t-th fixed-sum outputs of the DMUs, which can be positive, negative, or zero. When $\delta_{tj} > 0$, the DMU must obtain δ_{tj} units of fixed-sum outputs from others to reach the equilibrium state. When $\delta_{tj} < 0$, the DMU must reduce δ_{tj} units to reach an equilibrium state. When $\delta_{tj} = 0$, the DMU reaches the equilibrium state. According to the perspective of this study, $\delta_{tj} > 0$ indicates that the region lacks financial resources and must obtain financial resources from other regions to reach an equilibrium state, while $\delta_{tj} < 0$ indicates that the region has excess financial resources, which can be allocated to other regions to reach the equilibrium state. When $\delta_{tj} = 0$, the region has reached an equilibrium state, with stable financial operation and sufficient resources.

3.4. The spatial econometric model

Given the interconnectivity between the Beijing–Tianjin–Hebei region, our study aims to explore the factors influencing financial efficiency while considering the relationship between these regions. To achieve this, we employ a spatial econometric model for our research. Three spatial weight matrices are introduced to describe the complex relationship between Beijing, Tianjin, and Hebei cities; namely, the geographic distance matrix, economic distance matrix, and economic geography matrix. Latitude and longitude are used to calculate the geographic distance matrix, GDP difference is used to calculate the economic distance matrix, and the economic geography matrix is the sum of the previous two matrices. The spatial econometric model (*i.e.*, the Spatial Dubin Model (SDM)) is formulated as follows:

$$Y_t = \delta WY_t + \alpha l_N + \beta X_t + \theta WX_t + \varepsilon_t. \tag{7}$$

Here, W represents the spatial weight matrix, l_N is the column vector with all elements of 1; δ is the error term; ε is the coefficient of WY; α is the coefficient of l_N; β is the coefficient of the explanatory variable X; θ is the coefficient of WX. The coefficients are the model's final output and refer to each item's contribution to the explained variable. The positive and negative coefficients indicate the contribution of the explaining variable to the explained variable.

4. Indicator description and selection

4.1. The selection of input and output indicators

The data of Beijing–Tianjin–Hebei in China from 2011 to 2019 is analyzed in this study. Data sources include the Wind database, the China Urban Statistical Yearbook, and the statistical yearbooks of Beijing–Tianjin–Hebei. The difference method is used to compensate for missing data. There are five initial input variables for

TABLE 2. Variable selection results.

M_k	Variable combinations								AIC	BIC	HQC
	X_1	X_2	X_3	X_4	X_5	Y_1	Y_2	Y_3			
M_1	1	1	0	0	1	1	1	1	1.615944	2.894059	−0.44321
M_2	1	1	0	0	1	1	1	0	3.615944	5.533116	0.527209
M_3	1	1	1	0	0	1	1	1	3.615944	5.533116	0.527209
M_4	1	0	0	1	0	1	1	1	3.615944	5.533116	0.527209
M_5	1	1	0	0	1	1	0	0	3.615945	5.533117	0.527211
M_6	1	1	0	1	0	1	1	1	3.616019	5.533191	0.527285
M_7	0	1	0	1	0	1	1	1	3.61609	5.533262	0.527355
M_8	0	0	0	0	1	1	1	1	3.705211	4.983326	1.646055
M_9	1	1	1	0	1	1	1	1	3.89937	5.177484	1.840213
M_{10}	1	1	0	0	1	0	0	1	5.381378	6.659493	3.322222

TABLE 3. Indicators of financial efficiency.

Type of variable	Variable	Symbol
Input variable	Number of employed people in the financial industry (Ten thousand people)	X_1
	Number of companies in the financial industry	X_2
	The digital inclusive financial index	X_5
Desirable output	The loan balance of financial institutions (Hundred million yuan)	Y_1
	The added value of financial industry (Hundred million yuan)	Y_2
	GDP (Hundred million yuan)	Y_3
Undesirable output	Non-performing loan ratio (%)	Y_4

financial efficiency at the city cluster; namely, the number of employed people in the financial industry (X_1), the number of companies in the financial industry (X_2), registered capital stock (X_3), the deposit balance of financial institutions (X_4), and the digital inclusive finance index (X_5). There are three output variables; namely, the loan balance of financial institutions (Y_1), the added value of the financial industry (Y_2), and GDP (Y_3). According to Le *et al.* [14] and Luo *et al.* [23], the development of digital finance has significantly contributed to improving regional financial efficiency. Therefore, the digital inclusive financial index is used as one of the input indicators for financial efficiency.

The efficiency calculation should consider the possibility of redundancy of information when there are multiple variables present. Input and output indicators are selected according to the AIC, BIC, and HQC variable screening models. The number of variable combinations is $K = \left(2^5 - 1\right) \times \left(2^3 - 1\right) = 217$. Table 2 lists the AIC, BIC, and HQC values in ascending order. As a result of space limitations, only the results of the top 10 combinations are shown. Among them, “0” and “1” indicate that the variable is “not selected” and “selected”, respectively.

The AIC, BIC, and HQC estimates for the combination M_1 are the smallest and contain the variables X_1, X_2, X_5, Y_1, Y_2, and Y_3. Therefore, the final input and output indicators in the financial efficiency evaluation of this paper are X_1, X_2, X_5, Y_1, Y_2, and Y_3, as shown in Table 3. Furthermore, after selecting the optimal input and output, the non-performing loan ratio is considered an undesirable output in accordance with Ma *et al.* [24] and Wijesiri *et al.* [41].

TABLE 4. The influencing variable factors of financial efficiency.

	Index	Statistical methods	Abbreviation
Explained variable	Financial efficiency	The undesirable output SBM model based on Shannon entropy	FE
Explanatory variable	High-quality economic development	Per capita GDP (Hundred million yuan)	HQED
	Business environment	Evaluation index system of the urban business environment in China	BE
	Financial development	The loan balance of financial institutions/GDP(%)	FD
		Deposit balance of financial institutions/GDP(%)	
		Financial practitioner	
	Innovation environment	Scientific expansion /GDP (%)	IN
		Number of patents granted	
		Innovation capability index	
Control variable	Regional infrastructure construction	Number of mobile phone users at year-end (Ten thousand people)	IC
	Industrial structure	Tertiary industry /GDP (%)	IS
	Openness level	Total imports and exports /GDP (%)	OP

4.2. The selection of influencing factor variables of financial efficiency

The financial efficiency measured by the SBM model based on Shannon entropy is the explained variable. The high-quality economic development, business environment, financial development level, and innovation environment are selected as explanatory variables, and the regional infrastructure construction, industrial structure, and openness level are selected as control variables. Details of the variables are provided in Table 4. The indicators of the business environment, financial development, and innovation environment are calculated by applying the CRITIC method based on the findings of the "Research on evaluation of doing business in Chinese cities" research group [29].

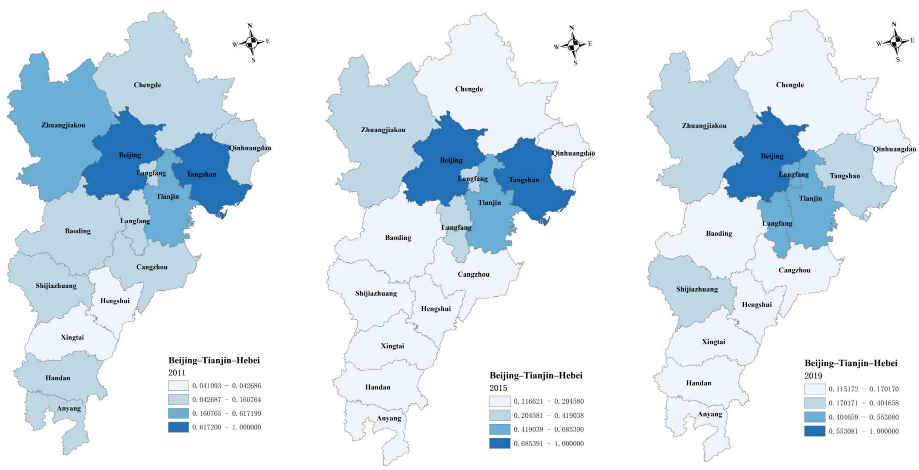
Since the explanatory variables involve many factors and some data from 2011 to 2013 are missing, the spatial econometric model only considers data from 2014 to 2019 for 14 cities in Beijing–Tianjin–Hebei region. The spatial econometric model is as follows:

$$\begin{aligned} \mathrm{FE} = {} & \delta \sum_{j=1}^{N} w_{ij}\mathrm{FE}_{jt} + \beta_1 \mathrm{HQED}_{it} + \theta_1 \sum_{j=1}^{N} w_{ij}\mathrm{HQED}_{jt} + \beta_2 \mathrm{BE}_{it} \\ & + \theta_2 \sum_{j=1}^{N} w_{ij}\mathrm{BE}_{jt} + \beta_3 \mathrm{FD}_{it} + \theta_3 \sum_{j=1}^{N} w_{ij}\mathrm{FD}_{jt} + \beta_4 \mathrm{IN}_{it} \\ & + \theta_4 \sum_{j=1}^{N} w_{ij}\mathrm{IN}_{jt} + \beta_5 \mathrm{IC}_{it} + \theta_5 \sum_{j=1}^{N} w_{ij}\mathrm{IC}_{jt} + \beta_6 \mathrm{IS}_{it} \\ & + \theta_6 \sum_{j=1}^{N} w_{ij}\mathrm{IS}_{jt} + \beta_7 \mathrm{OP}_{it} + \theta_7 \sum_{j=1}^{N} w_{ij}\mathrm{OP}_{jt} + \varepsilon_{it} \end{aligned} \tag{8}$$

where δ is the spatial autoregressive coefficient; ε_{it} is the error term; β, δ, and θ are the parameters to be estimated.

TABLE 5. The results of financial efficiency of cities in Beijing–Tianjin–Hebei.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Avg	Rank
Beijing	0.99	0.99	0.99	0.99	0.98	0.99	0.99	1.00	1.00	0.99	1
Tianjin	0.62	0.68	0.69	0.71	0.69	0.66	0.68	0.60	0.55	0.65	3
Zhuangjiakou	0.45	0.45	0.45	0.45	0.42	0.41	0.46	0.44	0.40	0.44	4
Chengde	0.07	0.07	0.12	0.12	0.12	0.12	0.11	0.11	0.15	0.11	12
Qinhuangdao	0.12	0.12	0.11	0.12	0.13	0.13	0.11	0.12	0.12	0.12	9
Tangshan	1.00	1.00	0.60	0.62	1.00	1.00	0.86	0.36	0.35	0.75	2
Cangzhou	0.08	0.08	0.12	0.13	0.15	0.19	0.17	0.16	0.15	0.14	8
Hengshui	0.04	0.05	0.08	0.10	0.12	0.13	0.13	0.13	0.16	0.10	14
Langfang	0.08	0.08	0.09	0.10	0.35	0.51	0.48	0.50	0.54	0.30	5
Baoding	0.07	0.09	0.09	0.11	0.12	0.15	0.14	0.14	0.13	0.12	11
Shijiazhuang	0.16	0.19	0.20	0.19	0.20	0.26	0.35	0.30	0.28	0.24	6
Xingtai	0.04	0.08	0.10	0.11	0.12	0.14	0.14	0.13	0.13	0.11	13
Handan	0.12	0.15	0.13	0.13	0.15	0.17	0.16	0.13	0.17	0.14	7
Anyang	0.07	0.09	0.08	0.11	0.16	0.14	0.15	0.13	0.12	0.12	10



(A) (B) (C)

FIGURE 2. The evolution of financial efficiency of Beijing–Tianjin–Hebei.

5. The results of financial efficiency and financial resource allocation in Beijing–Tianjin–Hebei

5.1. Beijing–Tianjin–Hebei financial efficiency

This paper uses the best input and output variable combination obtained by the variable selection model for evaluation, and the SBM model based on Shannon entropy is used for measurement. Table 5 presents the results of the financial efficiency of cities in Beijing–Tianjin–Hebei from 2011 to 2019.

As demonstrated by Table 5 and Figures 2 and 3, Beijing ranks first in terms of its average financial efficiency of 0.99, with a significant advantage in the Beijing–Tianjin–Hebei region. In addition, the financial efficiency of Beijing has been steadily developing from 2011 to 2019. Tangshan ranks second, averaging 0.75 in financial efficiency. The financial efficiency of Tangshan, however, has been subject to considerable fluctuations from 2011

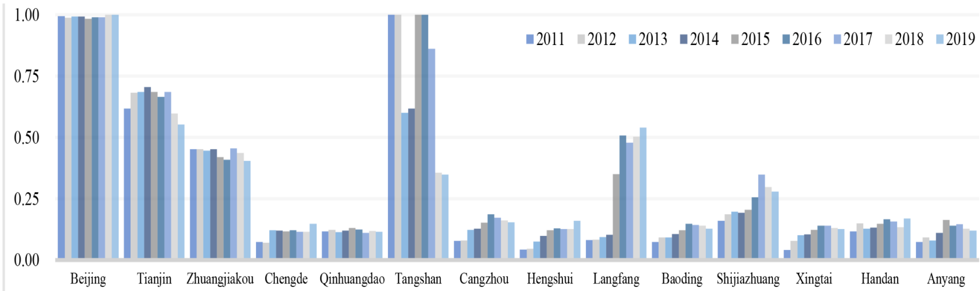


FIGURE 3. Financial efficiency fluctuations of Beijing–Tianjin–Hebei.

to 2019, with its efficiency being relatively high in 2011, 2012, 2015, and 2016. Although Tangshan's economic development is lower than that of Beijing and Tianjin, its non-performing loan (NPL) ratio is much lower than in other cities, especially in the years above when it was below 0.05%. Tianjin ranks third, with a financial efficiency value of 0.65. Areas surrounding Beijing also display advantages due to Beijing's financial development. Tianjin's financial efficiency increased between 2011 and 2014 but then declined. By 2018 and 2019, it has dropped to 0.60 and 0.55 respectively. This is mainly because the financial market in Tianjin entered a period of adjustment after 2017, resulting in a decline in the growth rate of the added value of the financial industry in 2018 and subsequently a resurgence in 2019. Zhangjiakou ranks fourth, with an average financial efficiency value of 0.44. The financial efficiency of Zhangjiakou developed steadily between 2011 and 2014, decreased in 2015–2016, increased significantly after 2017, and then decreased again. The reason for this phenomenon is the 18.5% increase in the balance of various loans in 2017. Langfang has an average financial efficiency value of 0.30, ranking fifth. Its financial efficiency has significantly increased from 2015 to 2019, likely due to its advantageous location, being proximate to Beijing and Tianjin. Thus, financial efficiency can be improved by leveraging locational advantages for development. Shijiazhuang boasts an average financial efficiency value of 0.30, ranking sixth. The financial efficiency of Shijiazhuang maintains an upward trend between 2011 and 2017 before declining. Moreover, the financial efficiencies of Chengde, Qinhuangdao, Anyang, and Handan have been relatively low and stable from 2011 to 2019 period. Conversely, Cangzhou, Hengshui, Baoding, and Xingtai have registered relatively low financial efficiency, yet have shown gradual increases between 2011 and 2019.

5.2. The financial resource allocation of Beijing–Tianjin–Hebei

Based on the research results of financial efficiency, the link between Beijing–Tianjin–Hebei financial resource allocation and financial efficiency is analyzed, which is useful for further analyzing the coordinated financial resource development and allocation scheme of the Beijing–Tianjin–Hebei. By the GEEFDEA theoretical model, different output indicators are fixed separately, including the loan balance of financial institutions (Y_1), the added value of the financial industry (Y_2), and GDP (Y_3). The adjustment amounts of the different indicators required for Beijing–Tianjin–Hebei cities to reach the equilibrium frontier are then obtained, provided in Tables 6–8.

Table 6 shows the adjustment amount required to achieve the effective frontier of financial efficiency in the Beijing–Tianjin–Hebei with the loan balance of financial institutions as fixed-sum outputs. According to the average value, the adjustment amount of Tianjin, Zhangjiakou, Tangshan, and Langfang is negative, indicating excess loan resources in these areas. In other words, due to this excess, there is an opportunity to redistribute loan resources to other regions within the Beijing–Tianjin–Hebei. Tianjin has the largest average annual absolute adjustment value of 1.64 trillion yuan, suggesting that it has the most surfeit financial resources and can allocate the largest amount of loans to other regions. Zhangjiakou's adjustment amount had a positive value during 2015–2016, indicating that its financial loan resources shifted from an overresourced state to an underresourced state in 2015, reaching an equilibrium in 2016, before returning to an overresourced state the following year. The adjustment amount of financial institutions' loan balance in Tangshan has been negative from 2011 to 2019, with

Table 6. Resource allocation optimization of the loan balance of financial institutions (1 trillion yuan).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Avg
Beijing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tianjin	−1.21	−1.84	−2.09	−1.98	−2.50	−1.47	−3.16	−0.40	−0.12	−1.64
Zhuangjiakou	−0.13	−0.04	−0.08	−0.18	0.02	0.00	−0.12	−0.49	−0.51	−0.17
Chengde	0.19	0.26	0.33	0.32	0.47	0.54	0.85	0.33	0.17	0.39
Qinhuangdao	0.14	0.27	0.30	0.20	0.34	0.43	0.64	0.14	0.09	0.28
Tangshan	−0.31	−0.35	−0.40	−0.43	−0.48	−0.42	−0.52	−0.47	−0.61	−0.44
Cangzhou	0.08	0.13	0.17	0.06	0.07	0.05	0.10	0.04	0.04	0.08
Hengshui	0.22	0.31	0.32	0.24	0.37	0.33	0.52	0.17	0.10	0.29
Langfang	0.01	0.09	0.07	0.00	−0.07	−0.30	−0.45	−0.62	−0.64	−0.21
Baoding	0.33	0.33	0.42	0.53	0.46	0.29	0.81	0.48	0.66	0.48
Shijiazhuang	0.23	0.18	0.14	0.43	0.41	0.00	0.00	0.33	0.47	0.24
Xingtai	0.23	0.34	0.31	0.37	0.42	0.24	0.59	0.27	0.26	0.34
Handan	0.04	0.08	0.23	0.25	0.25	0.10	0.46	0.28	0.09	0.20
Anyang	0.19	0.22	0.27	0.18	0.22	0.22	0.27	−0.04	0.00	0.17

an average annual resource surplus of 0.44 trillion yuan. As the financial industry has developed in Langfang, the loan balance has shifted from positive to negative, and loan resources have moved from being in short supply to being in excess.

Beijing's adjustment amount is 0, indicating that the loan resources in Beijing are adequate and have attained a state of equilibrium. Beijing's financial efficacy has been rated the highest, yet it does not experience a surplus of loan resources and instead, its financial resources have operated smoothly from 2011 to 2019.

The adjustment amount of loan balance in the cities of Chengde, Qinhuangdao, Cangzhou, Hengshui, Baoding, Shijiazhuang, Xingtai, Handan, and Anyang is positive, indicating that these regions have insufficient financial resources and must obtain loan resources from other regions in order to achieve the public equilibrium frontier effectively. Among them, Baoding's adjustment amount is positive and the largest, indicating that it needs to acquire the most loan resources from other regions to reach the effective frontier. Shijiazhuang's adjustment amount is 0 between 2016 and 2017, showing that it has achieved equilibrium. This was likely attributable to a swift enhancement in financial efficiency in 2015 and 2016. Anyang had surplus resources and achieved equilibrium between 2018 and 2019, which could be ascribed to the betterment of financial efficiency in 2013–2017.

Table 7 displays the adjustment amount required to reach the financial efficiency effective frontier in the Beijing–Tianjin–Hebei when the added value of the financial industry is the fixed-sum outputs. Based on the average value, the adjustment amounts of Beijing, Tianjin, Tangshan, and Langfang are negative, indicating that the added value of financial industry resources in these areas is surplus and can be redistributed to other areas in Beijing–Tianjin–Hebei region. In particular, the absolute value of Tianjin's adjustment amount is the largest, indicating that it has abundant financial resources. Consequently, Tianjin can allocate the most loan resources to other regions, with an average annual allocation of 92.86 billion yuan to regions in Beijing–Tianjin–Hebei. Beijing's adjustment amount during 2012–2017 is 0, and the remaining years are negative. Despite Beijing's financial efficiency being rated the highest, it did not have excess added value from the financial industry during 2012–2017. The adjustment amount of Tianjin's added financial industry value was negative in 2011–2018 and 0 in 2019, showing that Tianjin was in excess of added value from the financial sector in 2011–2018. Tangshan's adjustment amount from 2011 to 2019 has been negative. However, its financial efficiency value is still not high, indicating that the output value from the financial sector is not the cause of its low financial efficiency. Langfang's adjustment amount from 2011 to 2014 is positive, suggesting insufficient output from its financial sector. As the

Table 7. Resource allocation optimization of the added value of the financial industry (100 million yuan).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Ave
Beijing	−24.8	0	0	0	0	0	0	−1599.2	−1200.5	−313.8
Tianjin	−756.5	−843.7	−1186.5	−1389.5	−1396.1	−942.4	−1582.3	−260.5	0	−928.6
Zhuangjiakou	15.3	73.5	127.2	37.5	182.9	100.9	0	262.6	270.8	119
Chengde	98.1	122.9	115.5	165.3	224	283.2	404.3	373.8	133	213.3
Qinhuangdao	83.5	87.2	150.7	125.5	162.8	213.3	303.4	261.8	185	174.8
Tangshan	−67.5	−133.5	−157.8	−201.3	−224.5	−159.8	−175.7	−191.7	−200.4	−168
Cangzhou	76.6	65.3	81.2	70.3	16.8	0	49.2	94.9	102.2	61.8
Hengshui	110.8	118.7	165.6	139.9	170.4	163.9	231	230.7	76	156.3
Langfang	30.8	66.1	96.6	75.8	−35.9	−233.4	−273.1	−293.1	−387.2	−105.9
Baoding	144.7	145.7	217.4	339.5	269.4	239.3	433.1	389.7	484.7	295.9
Shijiazhuang	119.1	109.1	20.4	207.2	181.8	0	0	118.8	243.3	111.1
Xingtai	107.5	132.7	135.6	200.3	229.8	164.5	280.2	282.8	218.8	194.7
Handan	0	18.9	124.5	159.4	161.9	109.2	244.1	294.2	56.1	129.8
Anyang	62.3	37.2	109.7	70.2	56.8	61.2	85.8	35.3	18.2	59.6

financial efficiency improved, its adjustment amount from 2015 to 2019 became negative, indicating an excess of output value from the financial sector.

The average adjustment amount of output value from the financial sector in cities such as Zhangjiakou, Chengde, Qinhuangdao, Cangzhou, Hengshui, Baoding, Shijiazhuang, Xingtai, Handan and Anyang is positive, indicating that the output value generated from these regions' financial sectors is inadequate. As such, it is essential to retrieve the public equilibrium effective frontier from other regions. Among them, Baoding has the largest adjustment amount of 29.59 billion yuan; in other words, it must obtain the most loan resources from other regions to reach the effective frontier. Anyang, meanwhile, needs to obtain at least 5.96 billion yuan from other regions to reach the said frontier. The adjustment amount of Cangzhou was 0 in 2016, at which point it reached an equilibrium state and remained positive for the rest of the year. This can be attributed to the accumulated financial resources from the city's increased financial efficiency in 2015. The changing state of Shijiazhuang's added value from the financial industry mirrors the changing trend of its loan balance. It reached a 0 adjustment amount in 2016–2017, indicating that it has also reached an equilibrium state. This is largely due to the marked improvement in its financial efficiency between 2015 and 2016.

Table 8 shows the adjustment amount required to achieve financial efficiency effective frontier when GDP is a fixed-sum output in the Beijing–Tianjin–Hebei regions. According to the average value, the adjustment amounts of Tianjin, Tangshan, Cangzhou, and Langfang are negative, indicating that the GDPs of these areas are in excess. Thus, these regions can distribute their surplus production value to other Beijing–Tianjin–Hebei regions. Among them, the absolute value of Tianjin's adjustment amount is still the largest, indicating that it has the most excess financial resources, with an average of 422.11 billion yuan of total output value available for allocation to other regions every year. The adjustment amount of Tianjin's added value by the financial industry was negative in 2011–2017 and 0 in 2018–2019. Therefore, Tianjin is in a state of excess total output value from 2011 to 2017 and then reached equilibrium after 2018. The adjustment amount of Tangshan's added value by the financial industry has been negative from 2011 to 2019, demonstrating a state of excess total output value. The adjustment amount of the output value of the financial industry in Cangzhou was negative in 2011–2014, 0 in 2015, and positive in 2016–2019. Consequently, Cangzhou had an insufficient total output value before 2014, reached equilibrium in 2015, and had an excess total output value after 2016. Furthermore, the adjustment amount of Langfang's added value by the financial industry is positive in 2011–2015, implying that the value of the financial industry is insufficient. With the improvement of financial efficiency, the adjustment amount

TABLE 8. Resource allocation optimization of total output value (100 million yuan).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Ave
Beijing	0	0	0	0	0	0	0	0	0	0
Tianjin	−3989.7	−4368	−2881.7	−5667.9	−7506.7	−6811.9	−6764	0	0	−4221.1
Zhuangjiakou	0	767.6	248.1	0	673.2	0	0	0	0	187.6
Chengde	701.7	739.9	728	996.5	1489	2505.2	1860.3	860.8	566.7	1160.9
Qinhuangdao	528.6	888.2	432.5	649.3	1165.2	1972.7	1409.2	323.8	383.2	861.4
Tangshan	−2003.1	−2146.4	−2309.8	−1832.6	−1812.1	−1933	−1633.8	−2121	−2573.2	−2040.6
Cangzhou	−134.8	−229.7	−378.4	−119.3	0	222.9	91.2	−317.1	−229.2	−121.6
Hengshui	793	910.8	446	774.2	1244.4	1517.9	1216.1	442.9	346.2	854.6
Langfang	119.3	445.6	202.9	142	9.2	−1386.9	−615.6	−1362.9	−1454.2	−433.4
Baoding	1308.7	914.2	1051.1	1421.5	1142.3	1347.9	1528.6	804.1	1560.9	1231
Shijiazhuang	826.6	185.3	788.4	1223.4	853.5	0	0	795.1	1053.4	636.2
Xingtai	1004.3	1130.2	984.7	1269.7	1348.5	1090.5	1310.8	641.3	665.4	1049.5
Handan	170.9	84.4	401.7	665.5	680.5	476.2	873.5	371	−138.1	398.4
Anyang	674.6	677.9	286.6	477.6	713	998.5	723.8	−438.1	−181.1	437

of Langfang's value of the financial industry is negative in 2016–2019, indicating that the added value of the financial industry is excessive.

Beijing's adjustment amount is 0, indicating that its total output value is sufficient and an equilibrium state can be attained without adjustment. Despite Beijing's financial efficiency being rated the highest, it did not have a surplus of total output value during 2011–2019, and its financial resources ran smoothly.

The average adjustment amount of GDP in cities such as Zhangjiakou, Chengde, Qinhuangdao, Hengshui, Baoding, Shijiazhuang, Xingtai, Handan, and Anyang is positive, indicating that the output value of these regions is insufficient. Public equilibrium effective frontiers must be obtained by receiving output resources from other regions. Among them, Chengde, Baoding, and Xingtai have relatively large adjustment amounts, which are 1160.9, 1231.0, and 1049.5, respectively. Accordingly, their financial resource levels are relatively low. Thus, they require the most loan resources from other regions to reach the effective frontier. Zhangjiakou's adjustment amount in 2011, 2014, and 2016–2019 is 0, which indicates that it has reached an equilibrium state. Its adjustment amount in the subsequent years is positive, suggesting that it needs other regions to obtain output resources to reach the effective frontier. The adjustment amount of Shijiazhuang's total output value was 0 in 2016–2017, signifying that it reaches the equilibrium state. This was largely due to the significant improvements in financial efficiency during 2015–2016. Anyang's adjustment amount was positive in 2011–2017 and negative in 2018–2019. Its total output value was low at the resource level in 2011–2017. As the development of financial efficiency decreases, it has a surplus of output resources in 2018–2019.

Comparing the adjustment amounts of the three outputs reveals that their adjustment amount in the Beijing–Tianjin–Hebei region are varied and follow certain rules. (1) Some cities have different fixed-sum output adjustments in opposite directions. For example, the adjustment amount of Cangzhou's loan balance and the contribution of the financial sector is either positive or zero, while its total output value is negative. Therefore, the reason for Cangzhou's low financial efficiency is the low output of its loan balance and the financial industry's added value. The output of the total output value meets the needs of financial development. Therefore, if the financial efficiency of Cangzhou is to be improved, the output ratio needs to be adjusted. By increasing the loan balance and adding more financial industry value, the excess output can be distributed to the surrounding cities in need while the total output value is maintained. (2) Some cities have exhibited different fixed-sum output lags after reaching equilibrium. For example, the loan balance of financial institutions in Zhangjiakou reached an equilibrium state in 2016. However, the added value of its financial industry did not reach equilibrium until 2017. The adjustment direction of different fixed-sum outputs is usually the same for most cities. For example,

TABLE 9. Global Moran's I of Beijing–Tianjin–Hebei financial efficiency in 2014–2019.

	Moran's I	Z	P-value
2014	0.37	3.72	0
2015	0.271	2.823	0.002
2016	0.25	2.633	0.004
2017	0.301	3.003	0.001
2018	0.308	3.414	0
2019	0.269	3.163	0.001

Shijiazhuang's three outputs as fixed-sum outputs all attained an equilibrium state in 2016–2017. The three outputs of Chengde, Qinhuangdao, Hengshui, Baoding, Xingtai, Handan, and other cities have all displayed a positive trend in 2011–2019 as fixed-sum outputs. In conclusion, it can be inferred that the above regions display a low rate of financial efficiency, lack financial resources, and require support from other regions.

5.3. Environmental factors affecting financial efficiency

5.3.1. Spatial autocorrelation test

Moran's I is a spatial statistic that illustrates spatial correlation and indicates that activity in one area is closely tied to activity nearby in terms of distance and economic factors. This paper uses sample data from 14 cities in Beijing–Tianjin–Hebei from 2014 to 2019 to calculate Moran's I with a composite weighted spatial weight matrix. The results are shown in Table 9.

As demonstrated by the results, Moran's I of financial efficiency is greater than 0 and statistically significant, suggesting that financial efficiency in Beijing–Tianjin–Hebei has a significant positive spatial correlation, suggesting the need to employ a spatial econometric model. In addition, the relationship between regions with strong financial efficiency (or between regions with weak financial efficiency) is relatively close. In contrast, the relationship between regions with large differences in financial efficiency is relatively lower. Moran's I shows an overall decrease in volatility from 2014 to 2019, which indicates a gradual decrease in the positive spatial correlation of Beijing–Tianjin–Hebei in that period. The reason for this may be that the financial efficiency of individual regions increases significantly from 2014 to 2019, increasing regional imbalances.

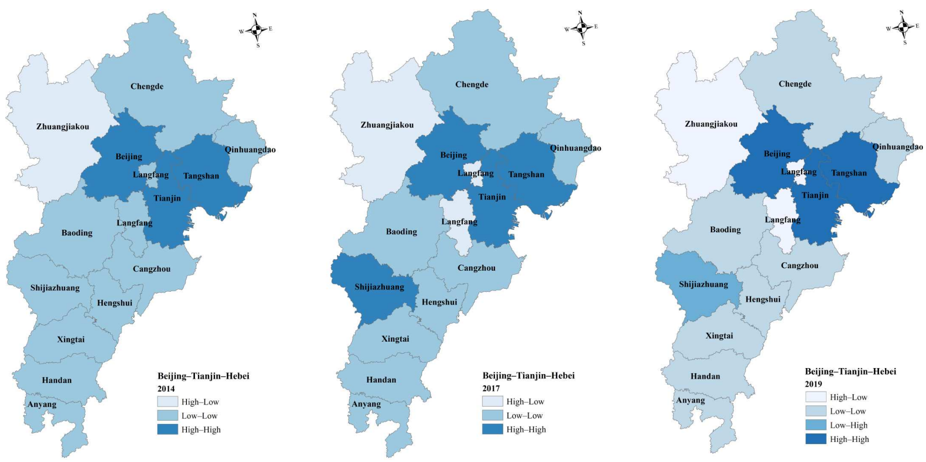
The global Moran's I examines cluster characteristics across regions and spaces. The presence of spatial correlation characteristics in local regions is tested using local Moran's I estimates of the financial efficiency of the Beijing–Tianjin–Hebei regions. The local Moran's I results are presented in Table 10, enabling the determination of spatial correlation characteristics between districts and counties with greater clarity.

As shown in Table 10, the aggregation of financial efficiency in the Beijing–Tianjin–Hebei regions continues to vary over time. Beijing, Tianjin, and Tangshan remain high–high aggregation areas, indicating that these three areas have high financial efficiency and that the financial efficiency of their surrounding cities is also relatively high. Meanwhile, Hengshui, Baoding, Xingtai, Chengde, Handan, Qinhuangdao, Cangzhou, and Anyang retain their positions in the low–low agglomeration areas, suggesting that the financial efficiency of these cities and their surrounding areas are relatively low. Shijiazhuang is in a low–high aggregation area, revealing that it has low financial efficiency but is surrounded by cities with high financial efficiency. Zhangjiakou and Langfang remain in the high–low aggregation area, implying that their financial efficiency is high, while the financial efficiency of surrounding cities is low.

The local Moran's I results are further verified by Lisa's plots, provided in Figure 4. Lisa's value > 0 indicates a positive spatial correlation, whereas Lisa's value < 0 indicates a negative spatial correlation.

Table 10. Local Moran's I of Beijing–Tianjin–Hebei financial efficiency in 2014–2019.

Year	High–high	Low–high	Low–low	High–low
2014	Beijing Tianjin Tangshan	–	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Shijiazhuang Langfang Cangzhou Anyang	Zhangjiakou
2015	Beijing Tianjin Tangshan	Shijiazhuang	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Cangzhou Anyang	Zhangjiakou Langfang
2016	Beijing Tianjin Tangshan	Shijiazhuang	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Cangzhou Anyang	Zhangjiakou Langfang
2017	Beijing Tianjin Tangshan Shijiazhuang	–	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Cangzhou Anyang	Zhangjiakou Langfang
2018	Beijing Tianjin Tangshan	Shijiazhuang	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Cangzhou Anyang	Zhangjiakou Langfang
2019	Beijing Tianjin Tangshan	Shijiazhuang	Hengshui Baoding Xingtai Chengde Handan Qinhuangdao Cangzhou Anyang	Zhangjiakou Langfang



(A) (B) (C)

Figure 4. Lisa's aggregation charts for 2014, 2017, and 2019.

5.3.2. LR and Hausman tests

LR and Hausman tests are performed to explore the spatial effect and select a model that matches the spatial interaction effect of the data. The test results are detailed in Table 11.

As demonstrated by Table 11, all of them are significant at the 1% significance level. Thus, the null hypothesis is rejected. The SDM model cannot be reduced to a spatial lag model (SLM) or a spatial error model (SEM). The result of the Hausman test (64.96 with a P-value of less than 1%) rejects the random effects, suggesting that the fixed effect model is the most suitable. In conclusion, the SDM model under fixed effects is the better choice for analyzing Beijing–Tianjin–Hebei's financial efficiency.

TABLE 11. LR and Hausman tests.

Test	Statistic	P-value
LR-sar	39.23	0
LR-sem	39.7	0
Hausman	64.96	0

TABLE 12. Results of Truncated regression and panel Tobit regression.

	(1) Tobit	(2) Truncated
x1	0.247^{**}	0.278^{***}
	−0.101	−0.085
x2	−0.00347	0.127
	−0.0755	−0.109
x3	-0.157^{***}	0.112
	−0.0557	−0.0745
x4	0.114	1.23
	−0.52	−0.802
x5	0.219^{**}	-0.203^{*}
	−0.106	−0.103
x6	0.0495	0.163
	−0.113	−0.15
x7	0.21	−0.336
	−0.217	−0.325
_cons	-3.774^{***}	-2.160^{*}
	−0.977	−1.228
sigma_u	0.155^{***}	
	−0.0353	
sigma_e	0.0915^{***}	
	−0.00825	
sigma		0.154^{***}
		−0.0195

5.3.3. The results of truncated regression and panel Tobit model

Due to the dependent variable being an efficiency indicator, which has certain characteristics, this article first applies commonly used truncated regression and panel Tobit model in research to conduct a simple analysis of the factors affecting financial efficiency [4, 26, 32]. The results are shown in Table 12.

Overall, high-quality economic development, financial development, and regional infrastructure construction significantly affect financial efficiency. Among them, the estimated result for economic high-quality development is positive, indicating that an improvement in economic high-quality development will lead to an increase in financial efficiency. The estimated result for financial development is negative, indicating that an improvement in financial development will lead to a decrease in financial efficiency. There are differences in the impact of regional infrastructure construction on financial efficiency in the two models, mainly because truncated regression cannot form a data panel after removing some factors.

5.3.4. The results of spatial econometrics

To explore the external environmental factors and spatial characteristics of financial efficiency, further research was conducted through spatial econometric models, and three spatial weight matrices were constructed. The

TABLE 13. The results of spatial econometrics.

	Geographic distance matrix		Economic distance matrix		Economic geography matrix	
	Time fixed	Entity fixed	Time fixed	Entity fixed	Time fixed	Entity fixed
HQED	0.297***	0.148	0.285***	0.145	0.169**	0.156
	(−0.0685)	(−0.0844)	(−0.078)	(−0.0835)	(−0.0638)	(−0.0855)
BE	0.069	−0.0578	0.0743	−0.0263	0.0744	−0.0273
	(−0.0749)	(−0.0516)	(−0.0686)	(−0.0459)	(−0.0633)	(−0.0472)
FD	−0.091	−0.0903**	0.235***	−0.114***	0.199***	−0.116***
	(−0.0584)	(−0.035)	(−0.0527)	(−0.0344)	(−0.0527)	(−0.0347)
IN	0.83	−0.548	−0.39	−0.0715	−0.635	−0.0402
	(−0.585)	(−0.370	(−0.471)	(−0.314)	(−0.449)	(−0.3410)
IC	0.0337	0.173	0.0589	0.0546	0.227**	0.0687
	(−0.0642)	(−0.123)	(−0.0682)	(−0.126)	(−0.07230	(−0.128)
IS	−0.134	0.183	0.321*	0.204	0.368**	0.215
	(−0.128)	(−0.0981)	(−0.132)	(−0.118)	(−0.133)	(−0.114)
OP	−0.151	0.327*	−0.344	0.369*	−0.437*	0.378*
	(−0.259)	(−0.16)	(−0.238)	(−0.162)	(−0.214)	(−0.164)
W*HQED	1.804**	0.604	−0.438*	0.0638	−0.540**	0.132
	(−0.661)	(−0.381)	(−0.188)	(−0.138)	(−0.209)	(−0.154)
W*BE	−0.208	−0.843	0.323*	0.0335	0.207	0.0279
	(−0.849)	(−0.454)	(−0.147)	(−0.0972)	(−0.183)	(−0.149)
W*FD	−2.822***	−0.2	0.133	0.0595	0.171	0.076
	(−0.755)	(−0.174)	(−0.118)	(−0.0593)	(−0.143)	(−0.0701)
W*IN	−0.732	−2.415	−1.217	0.207	−3.454**	0.303
	(−4.4)	(−2.232)	(−0.984)	(−0.629)	(−1.285)	(−0.999)
W*IC	2.328**	−0.555	0.151	−0.186	0.827***	−0.334
	(−0.884)	(−0.584)	(−0.126)	(−0.166)	(−0.216)	(−0.234)
W*IS	−3.621**	0.193	−0.327	−0.0829	−0.487	−0.0585
	(−1.289)	(−0.15)	(−0.291)	(−0.151)	(−0.372)	(−0.149)
W*OP	−0.413	4.404	0.0549	0.38	−0.226	0.463
	(−5.115)	(−2.885)	(−0.477)	(−0.271)	(−0.533)	(−0.367)
Spatial	−0.346	−0.67	−0.23	0.241	−0.218	0.299
rho	−0.431	−0.405	−0.18	−0.153	−0.209	−0.177
Variance	0.00918***	0.00216***	0.0104***	0.00234***	0.00834***	0.00231***
sigma2_e	−0.001	0	−0.001	0	−0.001	0
R^2	0.171	0.419	0.795	0.602	0.751	0.467

Notes. Standard errors are in brackets, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

selected explanatory variables and the dependent variable were inputted into the spatial econometric model, and the results are shown in Table 13.

The estimation coefficient and spatial lag term (W*HQED) of high-quality economic development (HQED) on financial efficiency are significantly higher under the time-fixed effect. By comparing the three weight matrices, the estimation coefficients of high-quality economic development (HQED) to financial efficiency are positive, 0.297, 0.285, and 0.169. It can thus be concluded that high-quality economic growth contributes to an increase in financial efficiency in the region. The spatial lag term (W*HQED) is positive (1.804) in the geographic distance matrix and negative (−0.438 and −0.540) in the economic distance matrix and economic geography matrix, thus indicating that a high-quality economy in a certain region can promote the financial efficiency of neighboring cities while hindering the financial efficiency of areas with similar economic conditions. The business environment's (BE) estimation coefficient on financial efficiency is insignificant. Its spatial lag term (W*BE) is significant in the economic distance matrix, yielding a positive value of 0.323. Therefore, it is evident

Table 14. The results of direct and indirect effects.

	Direct effect		Indirect effect		Total effect	
	Time fixed	Entity fixed	Time fixed	Entity fixed	Time fixed	Entity fixed
HQED	0.194^{**}	0.170	-0.522^{**}	0.239	−0.327	0.408
	(0.0692)	(0.0900)	(0.200)	(0.238)	(0.173)	(0.276)
BE	0.0631	−0.0287	0.189	0.0332	0.252	0.00454
	(0.0649)	(0.0504)	(0.162)	(0.227)	(0.152)	(0.256)
FD	0.201^{***}	-0.110^{**}	0.125	0.0594	0.326^{*}	−0.0501
	(0.0501)	(0.0339)	(0.139)	(0.105)	(0.159)	(0.115)
IN	−0.510	−0.0166	-3.054^{*}	0.397	-3.563^{**}	0.380
	(0.445)	(0.374)	(1.231)	(1.512)	(1.309)	(1.768)
ID	0.198^{**}	0.0493	0.688^{**}	−0.432	0.886^{***}	−0.382
	(0.0680)	(0.129)	(0.213)	(0.346)	(0.251)	(0.379)
IS	0.402^{**}	0.223^{*}	−0.503	−0.0125	−0.101	0.211
	(0.128)	(0.111)	(0.321)	(0.204)	(0.385)	(0.188)
OP	-0.448^{*}	0.421^{*}	−0.133	0.819	−0.580	1.240
	(0.210)	(0.184)	(0.475)	(0.655)	(0.610)	(0.786)

that enhancing the urban business environment can result in higher financial efficiency in similar-geographically regions. Additionally, the financial development level (FD) estimates of financial efficiency are significantly valid in all three matrices. Nevertheless, the direction of the results under the time-fixed effect is inconsistent with that under the entity-fixed effect. In further two-way fixed model estimation, the estimation results of the three matrices are significantly negative (−0.283, −0.150, and −0.156), indicating that financial development inhibits the improvement of financial efficiency in the region. Its spatial lag term (W*FD) is significantly negative (−2.822) in the geographic distance matrix, which suggests that financial development has an inhibitory effect on financial efficiency in surrounding areas. The estimates of innovation environment (IN) on financial efficiency are not significant. Its spatial lag term (W*IN) is significantly negative (−3.454) in the economic geography matrix, indicating that improving innovation environments hinders financial efficiency in surrounding areas with similar economic conditions. It is estimated that infrastructure construction (IC) had a significant impact (0.227) on financial efficiency in the economic geography matrix, indicating that regional infrastructure construction contributes to improving financial efficiency in the region. The spatial lag term of infrastructure construction is significantly positive in both the geographic distance matrix and economic geography matrix (2.328 and 0.827), illustrating that infrastructure construction positively impacts the financial efficiency of regions with similar distances. The estimated results of financial efficiency by industrial structure (IS) are significantly positive in both the economic distance matrix and economic geography matrix (0.321 and 0.368), indicating that industrial restructuring has a driving effect on improving financial efficiency in the region. Its spatial lag term (W*IS) is significantly negative (−3.621) in the geographic distance matrix, indicating that upgrading industrial structures could inhibit improving financial efficiency in the surrounding areas. The openness level (OP) estimates in both the geographic distance matrix and the economic distance matrix are significantly positive, with values of 0.327 and 0.369, respectively. In the economic geography matrix, the direction of the results under the time-fixed effect is inconsistent with that under the entity-fixed effect. Furthermore, the estimation results of the double-fixed model are all positive (0.234, 0.339, and 0.256), suggesting an increase in financial efficiency in the region as openness increases. Finally, the estimation results of its spatial lag term (W*OP) are not significant.

To gain a better understanding of the direct and indirect effects of each factor on financial efficiency, the economic geography matrix is chosen to decompose the influence of each contributing factor. The results are shown in Table 14.

According to the results, the direct effects of high-quality economic development (HQED), financial development level (FD), infrastructure construction (IC), industrial structure (IS), and openness level (OP) are significant, indicating that these indicators will affect the financial efficiency of the region. The indirect effects of high-quality economic development (HQED), innovation environment (IN), and infrastructure construction (IC) are significant. Among them, the indirect effect of high-quality economic development (HQED) and innovation environment (IN) on financial efficiency is estimated to be, at -0.522 and -3.054 respectively. In contrast, the estimated indirect effect of financial efficiency through infrastructure construction (IC) is positive, at 0.688. Therefore, an increase in high-quality economic development (HQED) and innovation environment (IN) tends to reduce the financial efficiency of surrounding cities or cities with similar economic conditions. The improvement of infrastructure construction (IC) will facilitate the improvement of financial efficiency in surrounding cities or cities with similar economic conditions. In addition, the innovation environment (IN) has a significantly greater indirect effect on financial efficiency. By combining the direct and indirect effects, it is evident that the indirect effects of high-quality economic development (HQED), innovation environment (IN), and infrastructure construction (IC) in the Beijing–Tianjin–Hebei regions are greater than the direct effects. Financial development level (FD), innovation environment (IN), and infrastructure construction (IC) all have a significant influence on financial efficiency. Among them, the total impact of the innovation environment (IN) on financial efficiency is the largest.

6. Conclusion and discussion

To improve the financial efficiency of the Beijing–Tianjin–Hebei region and optimize the allocation of financial resources, this article first achieves an accurate measurement of regional financial efficiency by utilizing the Shannon-based SBM model. Subsequently, the GEEFDEA model is employed to determine a precise allocation plan of financial resources that will improve the efficiency of the Beijing–Tianjin–Hebei region. Finally, the impact of external environmental factors on financial efficiency is analyzed through econometric models. The conclusions and discussions are as follows:

(1) According to the measurement results of financial efficiency, the development of financial efficiency in cities across the Beijing–Tianjin–Hebei region is uneven. Cities such as Beijing, Tianjin, and Zhangjiakou have high and stable levels of financial efficiency. The financial efficiency levels of Tangshan, Langfang, and Shijiazhuang are high but fluctuate considerably, whereas the financial efficiency of other cities is low and remains relatively stable. Li and Wang [15] suggested considering the nature and impact of inequality in the Beijing–Tianjin–Hebei regions when evaluating how to advance Beijing–Tianjin–Hebei financial integration. Based on the spatial aggregation of financial efficiency, it can be determined that Beijing, Tianjin, Tangshan, and the cities in their vicinity possess high financial efficiency. Meanwhile, Hengshui, Baoding, Xingtai, Chengde, Handan, Qinhuangdao, Cangzhou, Anyang, and the cities around them have low financial efficiency. Shijiazhuang has a low financial efficiency value, but is surrounded by cities with high financial efficiency. Zhangjiakou and Langfang have high financial efficiency, but their surrounding cities have low financial efficiency.

(2) According to our research on the allocation of financial resources, the financial conditions of Beijing, Tianjin, and Tangshan have superior development trends. However, Beijing does not possess a financial resource surplus, whereas Tianjin and Tangshan do have more of a surplus. In terms of financial resource allocation, Boso *et al.* [2] studied how to invest the idle financial resources of enterprises for sustainable development under different conditions of market pressure and political connection, whereas Surana and Anadon [34] explored and compared the establishment of domestic renewable energy technology innovation systems in China and India using financial resources. The loan balance, added value of the financial industry, and total output value in different regions of Beijing–Tianjin–Hebei are different as fixed-sum output adjustment amounts and conform to certain rules. Some cities have different orientations of fixed-sum output adjustment in opposite directions, such as Cangzhou. By doing so, the key factors impeding the improvement of the city's financial efficiency can be determined. Some cities have a time lag before fixed-sum outputs reach equilibrium. For instance, while the loan balance from the financial institutions of Zhangjiakou achieved equilibrium in 2016, the added value of the financial sector only reached equilibrium in 2017. Some cities in

Beijing–Tianjin–Hebei have the same orientation of fixed-sum output adjustment in the same year and are positive, showing that the regional financial efficiency is relatively undeveloped and lacks financial resources. Consequently, these cities need to bring in financial resources from other areas.

(3) All the variables studied have a certain impact on the financial efficiency of the Beijing–Tianjin–Hebei region. Among them, financial development, innovation, and infrastructure construction significantly impact the financial efficiency of the regions. In particular, high-quality economic development, infrastructure construction, industrial structure upgrade, and the level of openness all have a positive effect on the region's financial efficiency, whereas financial development has an inhibitory effect. Improving high-quality economic development and infrastructure construction will promote the financial efficiency of surrounding cities. Moreover, improvements to financial development, innovation environment, and industrial structure upgrades hinder the development of financial efficiency in surrounding areas. High-quality economic development has a negative effect on the financial efficiency of regions under similar circumstances. At the same time, improvements to the urban business environment will positively affect the financial efficiency of regions with similar economic conditions. Yıldırım and Mullineux [51] explored the economic environment of a city evolving into becoming a financial hub by utilizing questionnaires. The inquiries covered the economy, political stability, urban infrastructure, and other factors, thus offering a reference for further research into the external environment of urban financial development.

The main limitation of the article is that the study only applied the GEEFDEA model for financial resource allocation based on a fixed-sum output perspective, which is relatively narrow. In the next step, further improvements could be made to the model to optimize the path while considering multiple factors with a fixed-sum output perspective.

7. Policy recommendations

As a result of the research, this paper presents the following policy recommendations for achieving "integrated" financial development in the Beijing–Tianjin–Hebei urban cluster:

(1) Pilot areas for financial reform and innovation should be established in the Beijing–Tianjin–Hebei region, and a multi-subject participation form of regional governance should be introduced to manage the region. To address the issue of unbalanced financial development in the Beijing–Tianjin–Hebei region, cross-regional cooperation should be strengthened and benefit-sharing must be insisted upon.

(2) All financial institutions should pay greater attention to promoting regional economic integration and adjust their strategic layout actively. They should strive to enable the cross-regional handling of financial services in the Beijing–Tianjin–Hebei area, maintain the normal flow of funds between regions, and effectively use those funds to their fullest extent. Additionally, all regions should create more service outlets, reinforce financial services, and both facilitate the integration of Beijing–Tianjin–Hebei and preserve its development.

(3) It is advisable to position the development of each region in the Beijing–Tianjin–Hebei region, making the division of labor more reasonable, and carrying out high-quality financial cooperation. The role of the government must be given full play in guiding and coordinating the development of the financial industry. When formulating financial resource allocation plans, the contribution of each region should be taken into account, helping to determine the supplier of financial resources and the recipient of financial resources. In the Beijing–Tianjin–Hebei region, the surplus financial resources of Tianjin, Tangshan, and other cities should ideally be allocated to cities lacking financial resources, such as Chengde, Qinhuangdao, and Cangzhou, so as to improve financial efficiency effectively.

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