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Land-Use Efficiency in Shandong (China): Empirical Analysis Based on a Super-SBM Model

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Abstract: A reasonable evaluation of land-use efficiency is an important issue in land use and development. By using a super-SBM model, the construction and cultivated land-use efficiency of 17 cities in Shandong from 2006 to 2018 were estimated and the spatial-temporal variation was analyzed. The results showed that: (1) The land use efficiency levels were quite different, and low-efficiency cities impacted the overall development process. (2) The efficiency values of construction land generally fluctuated and rose, meaning that room remains for future efficiency improvements. Cultivated land generally showed a high utilization efficiency, but it fluctuated and decreased. (3) The construction land-use efficiency was highest in the midland region, especially in Laiwu city, followed by the eastern region and Qingdao city, and the western region. The spatial variation in cultivated land presented a trend of “high in the middle, low in the periphery,” centered on Jinan and Yantai city. (4) Pure technical efficiency was the main restriction driving inefficient utilization in the western region, while scale efficiency played that role in the east. Based on the findings, policy suggestions were proposed to improve the land-use efficiency in Shandong and promote urban sustainable development.

Keywords: land use; efficiency level; super-SBM model; Shandong Province; construction land; cultivated land

1. Introduction

Land provides the space for human survival and urban expansion. It plays an important supporting role in urban economic development. However, with China’s transformation from a traditional rural society to a modern urban society, the phenomenon of farmland conversion has caused excessive losses of agricultural land. Simultaneously, there are also problems with the extensive and inefficient use of construction land in China [1]. As China enters a new period of economic transformation and upgrading [2], the demand for land resources in China will remain high and continue to increase [3], and the contradiction between the use of land resources and sustainable economic growth will grow to be increasingly prominent [4]. Due to the scarcity of land resources, a development model based on the expansion of land is no longer sustainable, as well as improving the utilization efficiency of stock land and promoting the redevelopment of inefficient land, have become the most realistic development paths. Therefore, it is crucial to evaluate the efficiency level, evolution trend, and spatial pattern of land use to save limited land resources and to promote sustainable urban development, which is why measurement has been the focus of land-use research in recent years. In this regard, construction and cultivated land are two important land resources; thus, exploring their rational allocation and use holds great value.
Land-use efficiency is a result of a complex system that consists of many natural, economic, and social factors. It is an indicator that reflects the degree of land use and also reflects the ability to promote the synergic development of the urban society, economy, and environment [5]. In addition to the social and economic output, land-use efficiency also emphasizes ecological benefits, emphasizing the balance between land development and environmental protection. As far as research methods are concerned, the current land-use efficiency assessment methods mainly include principal component analysis (PCA), stochastic frontier analysis (SFA), data envelopment analysis (DEA), the slack-based measure (SBM), SBM-undesirable, and super-SBM models. Using these methods, many studies have been conducted on the evaluation of construction land-use efficiency and cultivated land-use efficiency at different temporal and spatial scales [5–10]. In terms of construction land, some scholars have evaluated land-use efficiency based on the output of land use per unit of a city [11,12], though more scholars use inputs and outputs, including land elements, for measurement [13–15]. Yu et al. [16] analyzed the land-use performance of China’s urban agglomerations from different perspectives. The results showed that the average urban land-use efficiency of urban agglomerations in China was not high. Jia et al. [17] found the urbanization characteristics in Chengdu using a three-stage DEA method, which also took the impacts of exogenous factors into consideration. In terms of cultivated land, previous studies have compared individual output and input factors to reflect the efficiency of cultivated land use. Current research focuses on multiple factors, using multiple input and output factors to evaluate farmland utilization efficiency and analyze the influencing factors. Baráth and Fertő [18] employed SFA and a latent class model (LCM) to measure the technical efficiency (TE) of Hungarian crop farms during 2001–2009. Shanmugam [19] used the SFA method to study the efficiency of agricultural production. The results showed that district-level efficiency largely depends on infrastructure, while cross-regional efficiency depends on environmental factors. Wang et al. [20] evaluated the agricultural efficiency of Anhui from 2000 to 2017 by using a super-SBM model and the Exploratory Spatial Data Analysis (ESDA) method. The results revealed that the overall efficiency was at a medium level and fluctuated upward.

In general, the existing literature has offered valuable research results, but some deficiencies remain: (1) Most of the existing literature evaluates the land-use efficiency of a single land type, and few studies explore the use efficiency of different land types through considering total factors and multiple perspectives. (2) Most of the current studies are based on DEA or SBM models. The ability of these models to evaluate effective units is relatively weak, which makes it impossible to conduct further efficiency rankings or to distinguish and compare effective units. (3) Insufficient research examines the evolution of the spatial pattern of urban land use efficiency in the study area.

To compensate for the deficiencies of existing studies, this study attempted to take the cultivated land and construction land of 17 cities in Shandong as the research objects, calculate the urban land-use efficiency of Shandong from 2006 to 2018 based on a super-SBM model and conduct a spatiotemporal difference analysis. To distinguish the land-use efficiency assuming constant returns to scale (CRS) and variable returns to scale (VRS), both a CRS and a VRS super-SBM model were adopted, and the scale efficiency of the land use over time was decomposed. In this way, we obtained a comprehensive understanding of the efficiency level, evolution trend, and spatial pattern of land use in various prefecture-level cities in Shandong Province, which allowed us to offer suggestions for realizing the intensive and efficient utilization of land resources and formulate scientific sustainable development policies.
2. Materials and Methods

2.1. Study Area

Shandong is located in the eastern part of the North China Plain and the lower reaches of the Yellow River. The region contains 17 prefecture-level cities (see Figure 1). As a major economic province, Shandong’s economic aggregate is always at the forefront of China, and it is in the peak stage of urbanization. The increasing demand for construction land during this period of economic and social development has led to an imbalance between supply and demand for land. At the same time, Shandong is also a large agricultural province, with early agricultural development and high agricultural land use. However, Shandong Province has a vast population and limited land, and by the end of 2007, the per-person cultivated land area of Shandong Province was only 0.081 hectares, while the per-person cultivated land area of 6 cities and 47 counties within Shandong was close to or below the critical line of 0.053 hectares determined by the Food and Agriculture Organization of the United Nations [21]. In the context of China’s “new normal” economy, the Shandong Provincial Government is stepping up efforts to promote intensive land use, which is worth paying attention to. Therefore, analyzing the contradiction between social and economic development and the limited land resources, the land-use efficiencies, and the changing trends of cities in Shandong Province is not only conducive to the scientific planning of land resources but also provides a direction for promoting the optimal layout and sustainable development of cities. According to the physical geographical features, Shandong can be further divided into three areas [22]: eastern (Qingdao, Yantai, Weihai, Weifang, Rizhao), midland (Dongying, Zibo, Jinan, Laiwu, Taian, Linyi), and western (Zaozhuang, Jining, Binzhou, Dezhou, Liaocheng, Heze).

![Figure 1. Location of the study area.](image-url)
2.2. Research Method

The DEA model originally proposed by Charnes et al. [23] uses a linear programming model to construct an effective production frontier to evaluate the relative efficiency of a decision-making unit (DMU) under multi-input and multi-output conditions. The DEA model does not require weight determination, thereby removing the influence of subjective factors and offering strong objectivity [24]. However, the traditional DEA model is radial and angular, and the improvement of ineffective DMUs only includes a proportional reduction (increase) in the input (output) and fails to consider input/output slack [25]. When the slack variable is nonzero, the land-use efficiency is usually overestimated. For this reason, Tone [26] proposed the SBM model, which is nonradial and addresses slack directly. However, regardless of whether a DEA or SBM model is used, the evaluation results may show multiple effective DMUs (where the calculated efficiency value is equal to 1). To further clarify the efficiency of effective DMUs, that is, to distinguish between those DMUs with an efficiency value equal to 1, Tone [27] proposed the super-SBM model. However, because the programming function of the super-SBM model is only applicable to effective DMUs, the SBM model must be understood before interpreting the super-SBM model.

2.2.1. SBM Model

Suppose the urban land use system has \( n \) cities that need to be evaluated. These cities are DMUs, denoted as \( DMU_i \) \((i = 1, 2, \ldots, n)\). For each DMU, the consumed \( m \) inputs and \( q \) outputs are denoted as \( x_i \) \((i = 1, 2, \ldots, m)\) and \( y_r \) \((r = 1, 2, \ldots, q)\), respectively. For the \( k \)th \( DMU_k \), \( x_k \) represents the \( i \)th input and \( y_k \) represents the \( r \)th output. The target function value of \( \rho \) is the efficiency value of the DMU. The efficiency calculated under the assumption of CRS is expressed as the TE. The SBM–DEA model can be described as in Equation (1):

\[
\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_{ik}^+}{1 + \frac{1}{q} \sum_{r=1}^{q} s_{rk}^-},
\]

subject to:

\[
\begin{align*}
X\lambda + s^- &= x_k, \\
Y\lambda - s^+ &= y_k, \\
\lambda, s^+, s^- &\geq 0.
\end{align*}
\]

In Equation (1), \( X = (x_{ij}) \in R^{m \times n} \), \( Y = (y_{ij}) \in R^{p \times n} \), \( X, Y > 0 \). The vectors \( s^- \) and \( s^+ \) indicate the input excess and output shortfall of this expression, respectively, and represent slack. \( \lambda \) is a non-negative vector in \( R^n \). Let an optimal solution for Equation (1) be \((\rho^*, \lambda^*, s^-, s^+)\).

If \( \rho^* = 1 \), \( DMU_k \) is relatively efficient. This condition is equivalent to \( s^- = 0 \) and \( s^+ = 0 \). That is, the TE of land use in the evaluated city is effective, and there is neither excessive input nor insufficient output in the land resource use.

If \( \rho^* < 1 \), \( DMU_k \) is inefficient. This condition is equivalent to at least an \( s^- \) of one, and \( s^+ \) is not equal to zero. In other words, it is necessary to improve the input and output of land resource utilization in the evaluated cities.

Assuming a VRS SBM model, the calculated efficiency is expressed as a pure technical efficiency (PTE). The VRS SBM model can be calculated by adding the constraint \( e\lambda = 1 \) on the basis of Equation (1), where \( e \) is a row vector with all element values equal to 1, i.e., \( e = (1, 1, \ldots, 1) \). Here, we will not go into the details of these. In addition, Equation (1) is a nonlinear programming function, and it can be transformed into a linear programming function using the method proposed by Charnes and Cooper [23].
2.2.2. Super-SBM Model

The programming function of the super-SBM model is only applicable to effective DMUs. For effective DMUs, the CRS super-SBM model can be described as in Equation (2):

$$\min \rho_{SE} = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s^-_i / x_{ik}}{1 + \frac{1}{q} \sum_{r=1}^{q} s^+_r / y_{rk}},$$

subject to:

$$\sum_{j=1, j \neq k}^{n} x_{ij} \lambda_j - s^-_i \leq x_{ik},$$
$$\sum_{j=1, j \neq k}^{n} y_{rj} \lambda_j - s^+_r \geq y_{rk},$$
$$\lambda_j, s^+, s^- \geq 0, \ j \neq k.$$

The VRS super-SBM model is based on Equation (2) but adds constraint conditions $\sum_{j=1, j \neq k}^{n} \lambda_j = 1,$ which we will not discuss in detail here.

2.2.3. Efficiency Decomposition

Assuming CRS, the efficiency result is expressed as the TE, whereas under VRS, the efficiency will represent the PTE. The scale efficiency (SE) can be defined as in Equation (3):

$$SE = \frac{TE}{PTE}.$$ 

The TE indicates the performance at both the current and future land-use scales, while the PTE reflects the sustainability performance of land use. With the increase in land scale, the SE shows the trend in land-use efficiency. If the SE is equal to 1, it indicates that the DMU is at an effective scale size [28].

2.3. Indicator System

This study evaluated urban land-use efficiency from the perspectives of construction land and cultivated land. Based on the connotation of the Cobb-Douglas production function, this study evaluated land-use efficiency using the relative value of the input/output ratio. In the selection of evaluation indicators, existing research results were used as a reference; the economic, social, and environmental benefits of urban land were comprehensively considered; a quantitative comparison and the availability of indicators were determined according to the actual situation of Shandong Province to determine the indicator system. The specific indicators are shown in Table 1.

1. Construction land input indicators: The area of construction land is one of the most important production factors in the study of construction land-use efficiency, and it is used to represent construction land input. The gross investment in fixed assets can comprehensively reflect the scale of investment, investment structure, and development speed, and can be used as a capital investment indicator. The number of secondary and tertiary industry employees represents the labor input of the construction land.

2. Construction land output indicators: The output indicators of construction land consist of the economy, society, and environment. GDP is one of the most important macroeconomic indicators, and construction land-use efficiency is closely related to the level of economic development. Therefore, the gross product of secondary and tertiary industries was selected to represent the economic benefits. The average salary of employees is an indicator of the social benefits of construction land, and the green coverage area is an indicator of its environmental benefits.
3. Cultivated land input indicators: The sown area of crops and the effective irrigated area represent the comprehensive cultivated land input and irrigated land input, respectively. The total power of the agricultural machinery and the consumption of chemical fertilizers represent the capital investment in cultivated land. The rural population represents the labor input of cultivated land.

4. Cultivated land output indicators: The gross agricultural production was selected to measure the economic output of cultivated land.

| Table 1. The input and output indicators. |
|------------------------------------------|
| **Target Layer** | **Indicator Layer** | **Indicators** | **Unit** | **References** |
| Construction land | Input index | Area of construction land | hm$^2$ | Jaeger et al. [29], Zhu et al. [30] |
|                    |             | Gross investment in fixed assets | $10^8$ RMB | Chen et al. [7], Wang et al. [31] |
|                    |             | Number of secondary and tertiary industry employees | $10^4$ persons | Yang et al. [32] |
|                    | Output index | Gross product of secondary and tertiary industry | $10^8$ RMB | Barbosa et al. [33] |
|                    |             | Average salary of employees | RMB | Yang et al. [32], Wang et al. [31] |
|                    |             | Green coverage area | hm$^2$ | Li and Fu [35] |
| Cultivated land | Input index | Sown area of farm crops | $10^3$ hm$^2$ | Feng et al. [36] |
|                    |             | Effective irrigated area | $10^3$ hm$^2$ | Feng et al. [36] |
|                    |             | Total power of agricultural machinery | $10^3$ kW | Kuang et al. [37], Yang et al. [38] |
|                    |             | Consumption of chemical fertilizers | $10^3$ tons | Yue and Li [39] |
|                    |             | Rural population | $10^4$ persons | Made and Ignatius [40] |
|                    | Output index | Gross agricultural production | $10^8$ RMB | Zhang et al. [41] |

2.4. Data Sources and Description

This study collected panel data of 12 indicators in 17 cities in Shandong from 2006 to 2018. Among them, the area of construction land, total investment in fixed assets, number of secondary and tertiary industry employees, the average salary of employees, and green coverage area were directly obtained from the China City Statistical Yearbook (2007–2019) (CCSY). Other data came from the Shandong Statistical Yearbook (2007–2019) (SSY). It should be noted that specific data for the total investment in fixed assets (2018) were not given in CCSY (2019); therefore, it was calculated based on the growth rate of fixed investment provided in the SSY (2019). The descriptive statistics of these variables are presented in Table 2.

| Table 2. Descriptive statistics of all the variables, 2006–2018, $N = 221$. |
|------------------------------------------|
| **Variables** | **Median** | **Std. Dev.** | **Minimum** | **Maximum** |
| Area of construction land (hm$^2$) | 16,255.204 | 10,081.686 | 4400.000 | 58,700.000 |
| Gross investment in fixed assets ($10^8$ RMB) | 1985.516 | 1494.856 | 140.421 | 8391.480 |
| Number of secondary and tertiary industry employees ($10^4$ persons) | 62.986 | 33.959 | 13.270 | 150.003 |
| Gross product of secondary and tertiary industry ($10^8$ RMB) | 42,467.524 | 17,880.888 | 11,870.900 | 91,651.000 |
| Average salary of employees (RMB) | 2790.339 | 1938.628 | 272.430 | 11,614.610 |
| Green coverage area (hm$^2$) | 7872.787 | 6042.112 | 875.000 | 39,229.000 |
| Sown area of farm crops ($10^5$ hm$^2$) | 661.846 | 381.988 | 76.428 | 1552.827 |
| Effective irrigated area ($10^5$ hm$^2$) | 661.846 | 381.988 | 76.428 | 1552.827 |
| Total power of agricultural machinery ($10^3$ kW) | 6727.192 | 3817.246 | 847.346 | 15,228.871 |
| Consumption of chemical fertilizers ($10^3$ tons) | 828.085 | 429.447 | 119.022 | 1674.992 |
| Rural population ($10^4$ persons) | 292.314 | 175.437 | 50.030 | 824.732 |
| Gross agricultural production ($10^8$ RMB) | 234.760 | 127.887 | 24.810 | 573.955 |
3. Results

3.1. Evolution of Construction Land-Use Efficiency over Time

3.1.1. Provincial Level

The construction land-use efficiency level of Shandong Province from 2006 to 2018 was measured based on the non-oriented super-SBM model. Taking Shandong Province as a whole, the efficiency values of all cities were averaged by year to obtain the comprehensive average value from 2006 to 2018, which is shown in Figure 2. Figure 2 shows that, generally, the average construction land-use efficiency of Shandong Province from 2006 to 2018 was in the order of PTE > SE > TE. Among them, PTE was in the 0.9–1.0 interval in most years, and the efficiency level was relatively high. The TE and SE were mostly concentrated in the 0.8–0.9 range, which shows that the low TE of construction land in Shandong Province was mainly restricted by the low SE, and there is still much room for improvement. From the perspective of changing trends, the construction land efficiency of Shandong Province fluctuated significantly from 2006 to 2018. In this period, during the Eleventh Five-Year Plan and Twelfth Five-Year Plan periods (referred to as the “two-five period” below), the TE and SE showed the same fluctuating trend of “rising-falling-rising”. During the two-five period, the government formulated a series of policies to control land development and strengthen land regulations [42]. Promoting the conservation and intensive use of land resources gradually became the starting point and goal of various land policies. Simultaneously, a series of plans were issued to implement new urbanization to optimize the spatial pattern of land use and improve the quality of urbanization [43]. The overall efficiency during the two-five period for construction land in Shandong did increase. However, the utilization efficiency of construction land from 2017 to 2018 showed a significant decline, which may have been related to the Ministry of Natural Resources of the People’s Republic of China in 2018 approving the conversion of 3,162.2155 hectares of agricultural land into construction land in 11 cities, including Jinan, Yantai, and Zibo [44]. Due to the massive increase in construction land, high input-output levels could not be reached in such a short period, resulting in a low construction land utilization efficiency. In summary, during the entire study period, the construction land-use efficiency of Shandong Province tended to diverge overall, but during the two-five period, it tended to converge. Aside from the international financial crisis in 2008 and the large amount of land approvals in 2018 that led to a sudden drop in utilization efficiency, the overall efficiency values showed a fluctuating upward trend, indicating that Shandong Province had achieved initial results in promoting conservation and intensive construction land use, but there is still great room for improvement.

3.1.2. Regional Level

As mentioned in Section 2.1, Shandong Province can be divided into eastern, midland, and western regions. A comparison of the TE, PTE, and SE of the construction land in these three regions (Figure 3) showed that the TE of the construction land in Shandong Province was structured as midland > western > eastern, while the PTE had the pattern of midland > eastern > western, and the SE was highest in the west, and lower in the midland and the east. Among them, the TE and SE trends in the midland and eastern regions tended to be roughly the same, and the SE was lower, indicating that the TE in the midland and eastern regions of Shandong Province was more affected by the SE. The lower TE was mainly due to the low SE; therefore, in the future, more attention should be paid to optimizing scale and structure in construction land use. The trends in the TE and PTE in the western region tended to be roughly the same, indicating that the western region was more affected by the PTE, and low construction land utilization efficiency was mainly caused by the low PTE. Although the SE was relatively high, the western region had a relatively unsophisticated economy; a low level of technological innovation and resource utilization; a relative dependence on agriculture, lakes, and mineral resources for economic development; it faced disadvantages from insufficient technology, capital, and human resources. Therefore, in the future development of the
western region, the government should proceed by improving the PTE by vigorously promoting technological innovation, improving management levels, increasing the proportion of secondary and tertiary industries (especially the latter), and increasing the industrial abundance and economic density. In addition, the TE and SE decreased in both 2009 and 2018. In 2009, they were mainly affected by the international financial crisis; in the east, in particular, where there was more developed coastal cities, an intense attraction from investors, and capital and technology close to international standards, the impact was relatively large. In 2018, due to the large increase in construction land area, the land-use efficiency fluctuated greatly in the process of the input–output and industrial structure adjustment, which affected the improvement of the land-use efficiency.

![Figure 2](image-url)  
**Figure 2.** Average construction land-use efficiency in Shandong during 2006–2018.

### 3.2. Spatial Evolution of the Construction Land-Use Efficiency

#### 3.2.1. Spatial Evolution of the Construction Land Technical Efficiency

Table 3 shows the TE, PTE, and SE of the construction land in 17 cities in Shandong Province in different years and summarizes the following spatial evolution characteristics. In terms of TE, the top three cities all had a TE higher than 1, achieving TE effectiveness in 2006, while the highest TE value of the bottom three cities was only 0.480. Among them, Laiwu city, which had the highest construction land-use TE, had an average value of 1.299, while Binzhou (0.353) had the lowest efficiency, at less than half that of Laiwu city, indicating that there was a clear imbalance in construction land utilization efficiency between cities in Shandong Province. In 2012, Liaocheng and Heze made great progress and became DEA efficient. Compared with 2012, in 2015, as the TE of low-efficiency cities increased, the overall TE of Shandong Province also increased. In 2018, except for Qingdao and Zibo, which had an obvious decline in efficiency, the remaining cities did not change significantly. Qingdao and Zibo added a large amount of construction land in 2018 [44]; therefore, their urban expansion rate was too fast. As a result, the input factors for construction land increased significantly, while the growth rate of the output factors was weak, resulting in a low efficiency. In general, Laiwu, Zibo, Dongying, Jining, and Qingdao had a higher TE of the construction land. Dezhou and Rizhao were at a good efficiency level (TE value: 0.8–1.0), while the other cities were at a moderate or low level. The many low-efficiency cities were the reason for the low efficiency of construction land in Shandong Province overall.
Figure 3. Average technical efficiency, pure technical efficiency, and scale efficiency of construction land across three regions in Shandong.
Table 3. Construction land-use efficiency of 17 cities for selected years \(^1\) (decomposing the TE and SE).

| Region       | 2006  | 2009  | 2012  | 2015  | 2018  |
|--------------|-------|-------|-------|-------|-------|
|              | TE    | PTE   | SE    | TE    | PTE   | SE    | TE    | PTE   | SE    | TE    | PTE   | SE    | TE    | PTE   | SE    |
| Qingdao      | 1.025 | 1.231 | 0.833 | 0.550 | 1.025 | 0.550 | 1.025 | 0.550 | 1.025 | 0.550 | 1.025 | 0.550 | 1.025 | 0.550 |
| Yantai       | 0.487 | 0.712 | 0.684 | 0.469 | 0.487 | 0.469 | 0.487 | 0.469 | 0.487 | 0.469 | 0.487 | 0.469 | 0.487 | 0.469 |
| Weifang      | 0.840 | 0.792 | 1.022 | 0.659 | 0.840 | 0.659 | 0.840 | 0.659 | 0.840 | 0.659 | 0.840 | 0.659 | 0.840 | 0.659 |
| Weihai       | 0.718 | 0.721 | 0.602 | 0.710 | 0.718 | 0.710 | 0.718 | 0.710 | 0.718 | 0.710 | 0.718 | 0.710 | 0.718 | 0.710 |
| Rizhao       | 0.801 | 0.802 | 0.754 | 0.764 | 0.801 | 0.764 | 0.801 | 0.764 | 0.801 | 0.764 | 0.801 | 0.764 | 0.801 | 0.764 |
| Eastern Average | 0.702 | 0.800 | 0.603 | 0.700 | 0.802 | 0.603 | 0.702 | 0.800 | 0.604 | 0.700 | 0.802 | 0.603 | 0.702 | 0.800 |
| Jinan        | 0.380 | 0.698 | 0.544 | 0.406 | 0.380 | 0.406 | 0.380 | 0.406 | 0.380 | 0.406 | 0.380 | 0.406 | 0.380 | 0.406 |
| Zibo         | 1.200 | 1.280 | 1.198 | 1.260 | 1.200 | 1.260 | 1.200 | 1.260 | 1.200 | 1.260 | 1.200 | 1.260 | 1.200 | 1.260 |
| Dongying     | 1.155 | 1.235 | 1.134 | 1.193 | 1.155 | 1.193 | 1.155 | 1.193 | 1.155 | 1.193 | 1.155 | 1.193 | 1.155 | 1.193 |
| Taian        | 0.545 | 0.571 | 0.597 | 0.619 | 0.545 | 0.619 | 0.545 | 0.619 | 0.545 | 0.619 | 0.545 | 0.619 | 0.545 | 0.619 |
| Laiwu        | 1.299 | 1.465 | 1.312 | 1.794 | 1.299 | 1.794 | 1.299 | 1.794 | 1.299 | 1.794 | 1.299 | 1.794 | 1.299 | 1.794 |
| Linyi        | 0.606 | 0.623 | 0.673 | 0.754 | 0.606 | 0.754 | 0.606 | 0.754 | 0.606 | 0.754 | 0.606 | 0.754 | 0.606 | 0.754 |
| Midland Average | 0.864 | 0.979 | 0.871 | 0.872 | 1.05 | 0.872 | 1.05 | 0.872 | 1.05 | 0.872 | 1.05 | 0.872 | 1.05 | 0.872 |
| Zaozhuang    | 0.520 | 0.528 | 0.983 | 0.660 | 0.520 | 0.660 | 0.520 | 0.660 | 0.520 | 0.660 | 0.520 | 0.660 | 0.520 | 0.660 |
| Jinjing      | 1.150 | 1.158 | 0.993 | 1.031 | 1.150 | 1.031 | 1.150 | 1.031 | 1.150 | 1.031 | 1.150 | 1.031 | 1.150 | 1.031 |
| Dezhou       | 0.801 | 1.137 | 0.705 | 1.076 | 0.801 | 1.076 | 0.801 | 1.076 | 0.801 | 1.076 | 0.801 | 1.076 | 0.801 | 1.076 |
| Liaocheng    | 0.635 | 0.724 | 0.877 | 0.758 | 0.635 | 0.758 | 0.635 | 0.758 | 0.635 | 0.758 | 0.635 | 0.758 | 0.635 | 0.758 |
| Binzhou      | 0.353 | 0.405 | 0.872 | 0.387 | 0.353 | 0.387 | 0.353 | 0.387 | 0.353 | 0.387 | 0.353 | 0.387 | 0.353 | 0.387 |
| Heze         | 0.502 | 1.000 | 0.502 | 0.640 | 0.502 | 0.640 | 0.502 | 0.640 | 0.502 | 0.640 | 0.502 | 0.640 | 0.502 | 0.640 |
| Western Average | 0.660 | 0.825 | 0.822 | 0.697 | 0.820 | 0.697 | 0.823 | 0.697 | 0.823 | 0.697 | 0.823 | 0.697 | 0.823 | 0.697 |

\(^1\) Due to space limitations, only results for selected years are presented.

3.2.2. Spatial Evolution of the Decomposition Efficiency of Construction Land

To further analyze the TE, it was decomposed into PTE and SE. In terms of the PTE, Laiwu, Zibo, Dongying, Qingdao, Jinjing, and Dezhou ranked as the top cities in 2006. These cities had relatively high efficiencies in the allocation and utilization of construction land resources. The PTEs of Heze, Rizhao, Linyi, and Dezhou were at a medium level, while the other cities had low efficiencies. In 2009, the PTE of Laiwu, Zibo, and Dongying increased and the PTE of construction land in the province showed an upward trend compared with 2006. In 2015 and 2018, the number of cities achieving a PTE increased significantly, and utilization efficiency also generally became higher. In terms of space, a pattern gradually formed with Laiwu in the midland and Qingdao in the east as the high-efficiency centers, while the surrounding cities remained relatively inefficient. In terms of SE, during the study period, no city in Shandong Province reached an SE value equal to 1. In comparison, cities such as Rizhao, Taian, and Dongying had higher SEs, indicating that they were better able to optimize the scale of the construction land. Cities with relatively low scale efficiency values included Jinan, Yantai, and Qingdao; these cities were facing a significant decrease in quality as a result of high construction speed in the process of construction land use. Therefore, in future land use, the government should not blindly pursue rapid economic growth but should focus on establishing a high-quality development model that prioritizes performance.

3.2.3. Regional Differences

The above analysis showed that the cities that displayed TE in Shandong Province from 2006 to 2018, such as Laiwu, Dongying, and Zibo, were mostly concentrated in the midland. Technical efficiency is related not only to the ability to allocate construction land resources but also to the efficiency with which that land is used. The cities that displayed PTE were mainly distributed in the east and the midland regions, such as Laiwu, Qingdao, and Dongying, which had a certain relationship with the economic development between regions. The higher the level of economic development is, the higher the level of technology and management, and the higher the pure technical efficiency. The cities with higher scale efficiency were mostly concentrated in the western region, such as Zaozhuang and Jinjing.

A further decomposition of the TE found that, overall, construction land utilization in Shandong Province was characterized by an ineffective SE but an effective PTE. For cities with a low TE, there were
two main types. The first type was most cities, which generally had a PTE lower than their SE, such as Binzhou and Linyi. The main reason for the low utilization efficiency of construction land in these cities was that the PTE was too low. This was because there was an extensive land use mode, where some land-use sites were scattered and disorderly, and some areas were improperly planned. Therefore, there was a sizeable disjunction between land use, land use/development, and efficient/intensive utilization. Therefore, to improve the utilization efficiency of construction land, these cities should focus on technological innovation and management, such as encouraging the development of new industries, strengthening organizational leadership and comprehensive management, and broadening the funding channels for land reserves. A few cities were of the second type, such as Jinan and Yantai, wherein the SE was lower than the PTE, indicating that the ineffectiveness of the SE was the root cause of the ineffectiveness of the TE. This type of city had a good economic foundation and location advantages, superior capital and technical conditions, and a large number of high-tech and emerging industries; therefore, the PTE was relatively high. However, there was a mismatch between scale and input-output, there was a phenomenon in which the functional positioning of the development area was blurred, and industry was not highly concentrated. Therefore, a focus should be on optimizing the economic scale, such as strengthening land approval and planning controls, standardizing land development models, and adopting various measures to promote the utilization of land resources.

3.3. Evolution of the Cultivated Land-Use Efficiency over Time

3.3.1. Provincial Level

Analysis of the cultivated land-use efficiency can reflect whether the distribution of cultivated land resources is reasonable and whether these resources are fully utilized. Figure 4 shows that during the study period, the use of cultivated land in Shandong Province was generally in the order of PTE > SE > TE. Among them, the PTE was basically maintained in the range of 0.9–1.0, while the SE and TE were mostly in the range of 0.75–0.85, reflecting that the low TE of Shandong Province was mainly due to restrictions from SE, which was similar to the result for the decomposition of the construction land-use efficiency. Judging from the trend changes, the overall efficiency of the cultivated land use in Shandong Province showed a fluctuating decline, indicating the instability of the cultivated land-use efficiency. The specific changes included a slight increase from 2006 to 2008. During this period, under the guidance of a series of land policies, Shandong issued various agricultural policies to create terminal, experiential, circular, and smart agricultural industries. To a certain extent, the cultivated land-use efficiency thus improved. In 2008–2012, volatility decreased, which may have been due to the 2008 financial crisis, as macroeconomic fluctuations and capital markets restricted agricultural production to a certain extent. In addition, urbanization rapidly increased the demand for land resources. In the process of occupying a large amount of arable land, input and output elements were wasted, and as a result, the cultivated land-use efficiency declined. In 2012–2016, the volatility increased; a bottleneck in land resource utilization gradually appeared in the urban development process, and all levels of government attached great importance to this issue and invested substantial effort into integrating land. Hundreds of comprehensive agricultural development projects were constructed or transformed to strengthen the protection of cultivated land, strictly observe the red line of cultivated land, standardize the circulation of rural land, and improve the balance between the occupation and compensation of cultivated land to improve the quality and efficiency of cultivated land use. The sharp decline from 2016 to 2018 was mainly due to the conversion and utilization of a large amount of cultivated land, the change in land-use types, and unreasonable aspects of land development and utilization, which led to a decrease in the cultivated land quality and the cultivated land-use efficiency.
3.3.2. Regional Level

The TE, PTE, and SE of the cultivated land in the three regions were compared next (Figure 5). During the study period, the TE and PTE of the cultivated land in Shandong were in the order of midland > east > west, and that of the SE was west > east > midland (note: because the PTE of Laiwu was much higher than that of other cities, to prevent the influence of extreme numbers on the results, Laiwu was not included in the calculation of the average PTE in the midland region). Among them, the PTE value in the midland was mostly in the range of 0.9–1, indicating that the input factors of the cultivated land utilization efficiency were relatively high. Most cities in the midland represent the main grain-producing areas in Shandong, which have a long history of traditional agricultural production and a rich experience in the utilization of cultivated land. The TE of the midland region tended to be consistent with the PTE. The SE fluctuated significantly, and its value was lower than that for PTE, indicating that the TE had a great influence on the TE. However, the main reason for the invalid TE value was that the SE was not high. Therefore, optimizing the scale and structure of cultivated land and developing various forms of moderate-scale operations should be future areas of focus for the midland region. The trends in the TE and SE in the east and west were roughly the same, indicating that the SE had a greater impact on the TE of cultivated land. Further analysis found that the PTEs of the eastern and western regions were generally lower than the SEs, reflecting that the main reason for restricting the TE was the PTE. At the same time, from 2016 to 2018, the SE of cultivated land in the east and west showed a significant decline, which was due to the newly allocated 142,753 hectares of basic farmland around the city in 2016 [45]. The conversion and utilization of a large amount of cultivated land and irrationality in land development/utilization led to a decline in the quality of cultivated land. Output factors increased at a slower rate than input factors; therefore, these areas could not reach economies of scale quickly. In general, the PTE and SE of the eastern and western regions were relatively high. To further improve the TE, we can start by further improving the PTE to improve the level of agricultural technology and resource utilization.
Figure 5. Average technical efficiency, pure technical efficiency, and scale efficiency of cultivated land across three regions in Shandong.
3.4. Spatial Evolution of the Cultivated Land-Use Efficiency

3.4.1. Spatial Evolution of the Cultivated Land Technical Efficiency

From the analysis of the TE, PTE, and SE of cultivated land at different times in Shandong Province in Table 4, the following spatial evolution characteristics were derived. In terms of the TE, the cities achieving TE in 2006 were Jinan, Yantai, Zibo, and Zaozhuang. These cities had no excess inputs and no output shortfalls, and the cultivated land was intensively used. The middle-level cities included Taian, Laiwu, and Huaiyang (TE values: 0.8–1.0), while the other cities had relatively low efficiencies. By 2015, the “high in the middle, low in the periphery” spatial characteristics that were centered on Jinan and Yantai gradually formed. Cities adjacent to Jinan and Qingdao had relatively high TEs, while the peripheral cities had relatively low TEs. In general, the TE of cultivated land use in Shandong Province did not change much during the study period. Cities with a higher efficiency were mainly located in the midland, such as Jinan, Zibo, and Laiwu. Cities with a lower efficiency were mainly located in the west, such as Liaocheng, Dezhou, and Heze, while cultivated land use was not standardized or industrialized, and the use of forms was extensive.

Table 4. Cultivated land-use efficiency of 17 cities for selected years 1 (decomposing the TE and SE).

| Region          | 2006 TE | 2009 TE | 2012 TE | 2015 TE | 2018 TE |
|-----------------|---------|---------|---------|---------|---------|
| Qingdao         | 0.753   | 0.753   | 1.000   | 0.707   | 0.707   |
| Yantai          | 1.083   | 1.129   | 0.999   | 1.048   | 1.091   |
| Weifang         | 0.812   | 1.232   | 0.659   | 0.783   | 1.141   |
| Weihai          | 0.578   | 0.617   | 0.937   | 0.564   | 0.949   |
| Rizhao          | 0.701   | 0.738   | 0.949   | 0.672   | 0.966   |
| Eastern Average | 0.785   | 0.894   | 0.901   | 0.755   | 0.846   |
| Jinan           | 1.121   | 1.125   | 0.997   | 1.268   | 1.270   |
| Zibo            | 1.041   | 1.045   | 0.997   | 1.029   | 1.067   |
| Dongying        | 0.707   | 1.018   | 0.695   | 0.607   | 0.650   |
| Tai'an          | 0.844   | 0.853   | 0.899   | 1.016   | 1.017   |
| Laiwu           | 0.830   | 2.586   | 0.321   | 1.016   | 2.763   |
| Linyi           | 0.743   | 1.018   | 0.730   | 0.722   | 1.002   |
| Midland Average | 0.881   | 1.274   | 0.788   | 0.943   | 1.295   |
| Zaozhuang       | 1.031   | 1.039   | 0.992   | 1.035   | 1.041   |
| Jinling         | 0.771   | 1.003   | 0.769   | 0.885   | 1.089   |
| Dezhou          | 0.617   | 0.624   | 0.989   | 0.581   | 0.612   |
| Liaocheng       | 0.666   | 0.682   | 0.977   | 0.771   | 0.820   |
| Binzhou         | 0.688   | 0.690   | 0.997   | 0.677   | 0.684   |
| Heze            | 0.597   | 0.670   | 0.891   | 0.497   | 0.545   |
| Western Average | 0.728   | 0.785   | 0.936   | 0.731   | 0.799   |

1 Due to space limitations, only results for selected years are presented.

3.4.2. Spatial Evolution of Cultivated Land Decomposition Efficiency

Assuming VRS, the PTE was measured. It can be seen that the PTEs of Laiwu, Weifang, Yantai, Jinan, Zibo, Zaozhuang, Dongying, Linyi, and Jining in 2006 were effective, while that of Tai’an was at a good level and the remaining cities were relatively inefficient. More than half of the cities achieved PTE, reflecting the relatively high level of cultivated land in Shandong Province. This result was consistent with the results of other scholars. Li [46] analyzed the utilization efficiency of cultivated land in Shandong Province from 1999 to 2008 and concluded that the cities with PTE were Jinan, Zibo, Tai’an, Laiwu, etc. Dou [47] analyzed the cultivated land-use efficiency in Shandong Province from 2005 to 2017 and found that cities such as Jinan, Zibo, Yantai, Tai’an, and Laiwu consistently had high PTE values. Although the agricultural output value of Laiwu was not high, the input resources of the cultivated land were fully utilized, and the PTE was at the forefront in Shandong. This may be related to the land improvement measures in Laiwu. Since 2006, Laiwu City has implemented five regulation projects in 2006, 2009, and 2010, adapting measures to local conditions and realizing the full flow and optimized allocation of cultivated land resources. By contrast, compared with 2006, the PTEs...
of Weifang, Zaozhuang, and Linyi declined in 2015. On the whole, the spatial distribution of the PTE had obvious gradations. The distribution of pure technically efficient and relatively high-efficiency cities over the years was mainly in line with the direction of the Yellow River, where the efficiencies of the western cities north of the Yellow River were relatively low, while those of the central cities south of the Yellow River were relatively high. As far as the SE is concerned, from 2006 to 2018, the SE of cities changed little, and most cities did not achieve SE. In 2006 and 2009, only Qingdao had an SE value of 1, thereby realizing SE and indicating that its input and output scale for cultivated land was at the frontier of SE. In 2012, the SE of Dezhou and Heze rose to 1, but in 2015, only Heze achieved SE. In terms of the spatial distribution, cities with a higher SE were mostly distributed in the west and east, while the midland had a relatively low SE, indicating that there is still room to better optimize the allocation of cultivated land resources in midland cities.

3.4.3. Regional Differences

Comparing the efficiency values of 17 cities, the cities with effective cultivated land TEs and PTEs in Shandong from 2006 to 2018 were mostly concentrated in the midland. Among them, the TE was represented by a “high in the middle, low in the periphery” distribution that was centered on Jinan and Yantai. For the PTE, the distribution of cities with a relatively high efficiency were roughly consistent with the trend of the Yellow River Basin: the western region located north of the Yellow River had a relatively low efficiency, while the midland region located south of the Yellow River had a relatively high efficiency. The SE was mainly characterized by “high in the east and west, low in the midland.” Specifically, the central region had a relatively high TE; although this region is located in the mountainous region of central Shandong, it has a long history of agricultural cultivation and rich experience in the use of cultivated land; therefore, the input and output efficiency of the cultivated land was relatively high. To further improve the cultivated land-use efficiency, attention should be given to improving the SE, and the relationship between cultivated land, labor, capital, and the scale of cultivated land management should be appropriately managed. For the eastern and western regions with relatively low TEs, the PTE was lower than the SE, indicating that the main reason for the low utilization efficiency of the cultivated land was that the PTE was too low. The low PTE was driven by relatively unsophisticated economic development in the west, which lacked a systematic and complete agricultural management system, insufficient agricultural technology innovation, and relatively unadvanced agricultural technology use and extension. Therefore, improvement in the utilization efficiency of the cultivated land in the western region should be based on technology and management, such as learning advanced agricultural technology and agricultural scientific research systems and supporting and cultivating leading agricultural enterprises. While some eastern coastal cities, such as Weihai and Yantai, had relatively good economic development, their industrial structure mostly focused on secondary and tertiary industry, and insufficient investment and development in the use of cultivated land resulted in low PTEs. Therefore, improvement in the cultivated land-use efficiency in the eastern region should be based on increasing management efforts, such as strengthening the basic construction of cultivated land and technological investment into the cultivated land.

4. Discussion

Comparing these findings with those of previous studies, Zhang [48] evaluated the construction land-use efficiency of Shandong Province from 2004 to 2012, and the results showed that the efficiency level differed significantly between regions and that there were a large number of extensive cities. In Li et al. [46], the TE of cultivated land in Jinan, Zibo, Zaozhuang, and Taian was fully utilized. Dou et al. [47] found that the utilization of cultivated land resources in Shandong was at a relatively high level and that the SE of cultivated land utilization was always lower than the PTE. These conclusions were basically consistent with the research in this paper. Dou also found that the cultivated land-use efficiency in Shandong Province increased slightly from 2016 to 2017, while the research in this study showed a significant decrease; this difference may have been due to the different selection of indicators.
In this study, "effective irrigated area" was added to the input index, that is, the input index included the cultivated land area that can be irrigated normally in the current year with irrigation engineering and equipment. The addition of this index aimed to more accurately reflect whether there were wasted cultivated land resources.

In general, the intensive use of land in the cities of Shandong Province is still in its infancy. The land-use efficiency in Shandong Province should be improved for the following three reasons. First of all, Shandong is now in the stage of transforming its economy from high-speed growth to high-quality development. With a background of increasingly scarce land resources in recent years, an excessive pursuit of the development scale and the neglect of development efficiency resulted in the low level of technical efficiency of land use in Shandong. Second, the regional disparity of the land-use efficiency in Shandong province indicates that the Shandong government’s ability to coordinate regional development needs to be improved under its limited land resources and financial capacity. Finally, the difference between the PTE and SE of construction land use in Shandong province reflects that the main means to promote urban development in Shandong province is still an increase in construction land area [49]. The relatively low PTE also indicates that the Shandong government should pay more attention to the optimal allocation of land resources. In a context with a shortage of existing land resources and the inability to obtain a large amount of idle land, the most targeted development path at present is to promote inefficient land redevelopment and improve land-use efficiency. In terms of construction land, the development of new technologies and industries, adjust the urban industrial structure, gradually upgrade from resource-consuming industries to technology-intensive industries, increase the proportion of tertiary industries, and change the method of resource utilization should be encouraged. In terms of cultivated land, targeted measures should be taken to narrow the differences in the utilization efficiency of cultivated land between cities according to the resources and economic levels of different cities. Meanwhile, the research and development of advanced production technologies should be encouraged to improve the technology utilization level of cultivated land.

Our estimates contained several uncertainties, which mainly came from the data collection limitations and the factors influencing land use in the urbanization process. Based on the perspective of green ecology, the output elements of land should consider undesirable output with negative externalities, which is covered by many scholars in their research. However, due to the lack of relevant indicator data, this study did not include these indicators. In addition, the use of land resources is a dynamic and complex system, and the index system selected in this article cannot fully cover the influencing factors of land use resources. More detailed research is needed in these areas in the future to improve estimations of the performance of land-use efficiency.

5. Conclusions

This study adopted the super-SBM model and selected 17 cities in Shandong as the research objects to explore and analyze the temporal and spatial evolution characteristics of the utilization efficiency of cultivated land and construction land in Shandong cities from 2006 to 2018. It drew the following main conclusions: (1) There was a large difference in the land-use efficiency between cities, and low-efficiency cities impacted the overall development process. In particular, more than half of the cities in Shandong were ineffective in terms of their construction land-use efficiency. The efficiency of land use showed that there are more cities with low efficiency, which restricted the development process of Shandong Province. (2) From a temporal perspective, the construction land-use efficiency in Shandong Province from 2006 to 2018 showed a fluctuating and rising trend, and there was still room for future efficiency improvement. The utilization efficiency of cultivated land was generally higher, but it fluctuated and decreased. (3) In terms of space, the utilization efficiency of urban construction land and cultivated land was highest in the midland, followed by the eastern and western regions. Among them, the spatial change trend in construction land showed a pattern of focusing on Laiwu city in the central region and Qingdao city in the east. The spatial variation trend in cultivated land presented an aggregation trend of “high in the middle, low in the periphery” that was centered on Jinan.
and Yantai city. (4) Pure technical efficiency was the main restriction driving inefficient utilization in the western region, while the scale efficiency was the main restriction in the eastern region. Regardless of whether it was farmland or construction land, very few cities achieved scale efficiency, and there was still a certain gap between the scale of land input and the optimal input–output scale in each city. According to the regional distribution, developing targeted policies to improve the efficiency of inefficient urban land use should be the focus of Shandong’s future development.

To promote the further improvement of land-use efficiency in Shandong Province, this study puts forward the following countermeasures based on the current situation and existing problems of land use in Shandong: (1) Scientific land planning using big-data analysis and simulation is an imperative means of monitoring or improving the spatial distribution of construction land and cultivated land [50]. (2) Take targeted measures to eliminate differences in the land-use efficiency according to different land resources and economic levels in different regions. In view of the low-level spatial agglomeration of land use in Shandong, the PTE is generally low, especially in the western region. The government should vigorously promote technological innovation in the western region and incorporate technological innovation to land use resources and management. It is also necessary to promote the construction of urban agglomerations, compile regional development plans, exchange needs with other cities, and improve the land-use efficiency through regional coordinated development. (3) For construction land, the government should strengthen the rational planning of construction land and attempt to construct innovative land areas in new urban development to transform the development of cities from factor and capital input into an innovation-driven one to improve the PTE [51]. (4) As for cultivated land, the scale efficiency needs to be improved. According to market-oriented development needs, the government should reasonably control the scale of cultivated land use to ensure the appropriate development of cultivated land. (5) Attention should be paid to the quality of environmental protection, and environmental protection investment should be increased. Green coverage area is an important factor that affects land-use efficiency. Increasing investment in environmental protection and improving the environmental output are effective ways to improve land-use efficiency.

In the future, given the concepts of rational development, adapting measures to local conditions, and persisting in sustainable development, the development pattern of national territory space should be constantly optimized to promote long-term development.

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