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Evaluating resource utilization efficiency in urban land construction of Yangtze river economic zone under technological progress

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Based on the economic models of DEA-Malmquist, this paper estimated the land utilization efficiency by considering dimensions such as energy, water and economic inputs in the Yangtze River Delta urban agglomeration from 2004 to 2016, and analyzed its spatial and temporal evolution pattern and characteristics. Then use the Tobit model to explore the main influencing factors, and examine the contribution of each influencing factor, such as technical progress. The research results show that the urban construction efficiency and the distance from the port have a "⌣" curve relationship, verifying the "center-periphery" theory of new economic geography. It is also found that the effective radiation distance of the current economic center Shanghai to the surrounding area is 361.5 km. The structural analysis of the efficiency of construction land shows that the market mechanism has not played a fundamental role in the allocation of construction land resources, the improvement of the quality of labor force, and the expansion of capital clustering with industry is the main driving factor to support the efficiency of construction land use in the Yangtze River Delta region. We suggest that more efforts will be needed to reform market mechanisms and improve technological progress in the near future.

KEYWORDS

Yangtze river delta, construction, resource efficiency, DEA-Malmquist model, coreperiphery theory

1 Introduction

Land has always been one of the essential constraint factors of economic production (Clark, 1977). This is the case in China, where urban construction land has expanded much faster in the past decades. During 2004 and 2018, the per capita construction land in Chinese cities is 134.61 square meters, far exceeding the national standard and other similar developing countries. In 1994, China implemented the tax-sharing reform and local governments were rendered highly economically oriented. The "authoritarian system of decentralization" and the "promotion tournament" system of local officials in effect, escalated the "tragedy of the commons" by excessively exploiting urban land for economic purposes. However, excessive urban sprawl not only reduced the environmental quality of the whole city region but also posed a great threat to the red line of arable land, resulting in serious food security problems. Improving land-use efficiency has become a crucial issue for the sustainability dilemma of urban development in China (Wang et al., 2018).

Land use efficiency also impacts economic growth, which has been intensively explored by the neoclassical economic paradigms. Kemp-Benedict et al. (2019) found that savings and investment functions changed due to land use, affecting the speed of capital accumulation. The research of Ball and Mankiw (2021) drew similar conclusions from the same theoretical lens, arguing that land eliminates dynamic inefficiency and breaks the golden rule of economic growth. At present, the concept of land use efficiency is widely used but still lacks a clear and universally accepted definition (Yu et al., 2019). However, despite the variances in definition and methods, they all measured efficiency by comparing inputs and outputs of urban land resources (Zhu et al., 2019; Gao et al., 2020; Han et al., 2020).

The Yangtze River Delta urban agglomeration, centered in Shanghai, consists of 25 prefecture-level cities in three provinces of Jiangsu, Zhejiang, and Anhui. It is one of the seven largest urban agglomeration regions in China. As the center of economic activities, port cities play an essential role in urban agglomerations (Yu et al., 2021), and its radiating effect also promotes the economic growth of the surrounding cities. Shanghai is an important port for the economic and social exchanges between China and the outside world. Yangshan in Shanghai is selected as the major port in the Yangtze River Delta urban agglomeration due to its geographical location. However, Hu et al. (2022) and Shen et al. (2019) found that the land-use efficiency of the Yangtze River Delta agglomeration decreased in the past 2 decades. Zhao et al. (2021) found that the land-use efficiency of the Yangtze River Delta areas was the lowest in China. Land use has become an obstacle to further development of the Yangtze River Delta urban agglomeration.

This paper studies the land-use efficiency in the Yangtze River Delta and explores what factors drive land-use efficiency dynamics and how it happened. Due to the lack of land use statistics in Shanghai, Yangshan Port is selected as the distant point, the research target areas of this paper are the 25 cities in the Yangtze River Delta urban agglomeration except for Shanghai, while our main purpose is to investigate the spatial distribution of land use efficiency levels in the Yangtze River Delta with Shanghai as the center. The second part of the paper reviews the research on construction land-use efficiency and the related theoretical debates. The third part introduces the research methods, measurement indexes and data sources. The fourth part analyzes the efficiency and influencing factors according to the empirical results. The last part is the conclusion and policy suggestions.

2 Literature review

2.1 Resource efficiency in land use

The research on land use originates from the school of Ecological Location in the 1920s, which described the spatial differentiation patterns and characteristics of urban land use and concluded some major urban land use patterns such as the axial development model, concentric model, fan model and the multi-core model (Liu et al., 2001). The market equilibrium theory, which is based on economic rationality, the second school gives explanations of urban land use from economic paradigms. They constructed the urban land use model, analyzed and explained the spatial distribution of urban land use by investigating economic activities (Dadashpoor et al., 2019; Thisse, 2019; Gaspar, 2020). In recent years, research on land use efficiency mainly focuses on agricultural production and urban planning (Long et al., 2020), while discussions about China mainly focus on land resource evaluation and management (Xie et al., 2020). Zhang et al. (2021) investigated land-use efficiency from the structural perspective, targeting both the macro level and marginal efficiency at the micro level. Pan et al. (2022) measured urban land use efficiency by taking the GDP of the unit built-up area as the output value. Wu et al. (2021) held the view that urban land use efficiency is the result of many influencing factors of nature, economy and society.

There are many research methods to measure land-use efficiency. Han and Zhang (2020) and Tian et al. (2021) measured the comprehensive land-use efficiency, agricultural land-use efficiency and urban construction land-use efficiency in China using the weighted average method, PCA (Principal Components Analysis) and DEA methods. With PCA and SFA (Stochastic Frontier Approach), Tang et al. (2021) used the PCA-SFA composite model to evaluate the urban land-use efficiency in Anhui province. Among them, there is proliferated literature using DEA methods to evaluate land-use efficiency (Koroso et al., 2021). The evaluation perspectives are comprehensive, and many popular concepts such as the green economy and environmental indicators are gradually included in the evaluation system (Wu et al., 2021). Many scholars analyze the efficiency of urban land use with other technical tools. Liu Y et al. (2020) revealed the spatial differentiation characteristics of urban land use efficiency by croup comparison of different cities. Liu et al. (2022) used GIS spatial analysis, index decomposition, and panel data models to study the temporal characteristics, regional discrepancies and influencing factors of land use efficiency. Zhang et al. (2022) established the spatial lag econometric model to explore the influencing factors of urban land use efficiency and the regional differences of the spillover effects. Jiaying and Yafen (2021) used Moran's I index to analyze the spatial autocorrelation of land-use efficiency and agglomeration characteristics of 110 prefecture-level cities in the Yangtze River Economic Belt. In addition, some scholars examined land-use efficiency from new perspectives. He et al. (2020) studied land-use efficiency from the perspective of land tax, investigating the problem of heterogeneous index data in the evaluation of land-use efficiency. Ge et al. (2021) integrated space technologies into the econometric model of the new economic geographical framework and explained the impact of the domestic and international market, as well as the spillover effects of space technology on urban land-use efficiency. Yao and Zhang, (2021) took county-level cities in Sichuan as research targets and explored the spatial relationship between traffic infrastructure construction and land-use efficiency.

2.2 The core-periphery theory of urban resource efficiency

The "core-periphery" spatial pattern of cities resulted from the evolution of urban systems. The "core-periphery" theory was originally put forward by Argentine economist Prebisch in 1949, who used "core" and "periphery" to describe the relationship between developed and developing countries. Friedman (1966) introduced this concept to regional economics. Dixit and Stigliz (1977) formalized monopoly competition, developing the new trade theory and location selection theory, and established the Dixit-Stiglitz model of conflicts between economic scales and diversified consumption. Krugman (1991) improved the D-S model in his paper Increasing returns and economic geography and constructed a two-region model of agriculture and industry through the Cobb-Douglas production function. This paper is regarded as the pioneering work of new economic geography. Krugman argued that the emergence of the "core-periphery" structure depends on the transportation cost, scale economy and the proportion of manufacturing in the national economy. Other scholars modified the "core-periphery" model with empirical evidence from other countries. Blanchard and Katz (1992) regarded regional specialization caused by the integrated market as arbitrary. Following their idea, scholars such as Liu J et al. (2020) believed that the spatial pattern of this specialization was then locked by external economic conditions, assuming that the huge differences in growth rates between regions of the US were the results of an inherently random economic process. Rye and Slettebak (2020) and Kaiser et al. (2018) investigated the labor market in Europe and found that compared with the US, labor mobility in Europe was insufficient, which lead to the widening wage gap and technological progress between countries and regions in Europe. Following the cyclic accumulation mechanism in the core-periphery theory, labor mobility leads to the expansion of the market size and an increase in economic profits and technological upgrades in the central region. In the global view, scholars such as Chen et al. (2020), Song et al. (2019), and Li and Du (2021) followed Fujita et al. (1999) and extended the model into a generalized spatial equilibrium model of multiple cities and industries and found that overall, there is a nonlinear relationship between economic and technological progress, resource efficiency and distance to the central cities. As further away from the central city, a city loses its advantages due to less industrial agglomeration, and economic growth is slowing down. However, in like vein, there is also a smaller chance for a local market to be squeezed by the central cities. Surprisingly, the increase in distance will protect and improve the economy of surrounding cities when the distance to central cities continues to increase. If the distance further increases, the peripheral cities no longer are attracted by the radiation effect of the central city and it will not be included in the local market. As a result, the urban economy will be stagnant.

Some studies about China have paid attention to the effects of the "core-periphery" theory. However, it rarely discussed the resource efficiency problems. For example, Pu et al. (2022) established a trade agglomeration model to study the welfare nature of the "core-periphery" model. Li and Li (2022) revised the model, considering the heterogeneity of workers in terms of skills and liquidity, it is easier to analyze the regional asymmetric trade cost problem. Duan et al. (2021) found that the gravity model modified from the original "core-periphery" model can better depict reality, using Spanish migration data. Asadi and Jafari Samimi (2022) studied the social desirability of agglomeration and the efficiency of policy intervention and found that under the condition that the trade cost is in the middle level, there is a stable equilibrium of partial agglomeration of enterprises in addition to the "core-periphery" equilibrium. Although there are few kinds of research on resource efficiency, some people have begun to pay attention to it in recent years. For instance, Dong et al. (2021) investigated the development of three metropolitan areas (the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Tangshan urban agglomerations) and concluded that the agglomeration of population and economy in the metropolitan area was still going on. Zhou et al. (2022) found that the environmental technology level of the Beijing-Tianjin-Hebei metropolitan area has been increasing continuously since the 1980s. Scholars such as Ye et al. (2022) and Cong et al. (2020) studied the relationship between urban economic growth and the distance to large ports by using China's city-level panel data. The results showed a nonlinear relationship, consistent with the predictions of the “core-periphery” theory. Cui et al. (2019) found that the labor productivity of the tertiary industry and the distance to major ports and regional core cities also showed a similar “∽” relationship. Considering these studies are just emerging, this paper will argue the “Core-Periphery” theory, with a focus on the Yangtze River Delta. Based on focusing on this region, this paper combines previous studies to select indicators, such as technological progress, water, and energy consumption and other indicators.

3 Methodology

3.1 Data envelopment analysis method and Malmquist productivity index approach

Data Envelopment Analysis (DEA) method is a model taking into account of multi-input and multi-output variables and uses nonparametric linear programming to measure the relative efficiency of decision-making units (DMUs), which has been widely employed to evaluate the construction land-use efficiency. Therefore, we use the DEA model to analyze the utilization efficiency of urban construction land in the Yangtze River Delta. In the process of analyzing consumption, we use the Malmquist index, which is mainly used to analyze the change in efficiency and measure technology progress in different periods. The application of DEA method and Malmquist productivity index approach is shown in Supplementary Appendix S1.

Production indicators are usually divided into four categories: land, capital, labor and entrepreneurial talents. The input indicators are selected from the perspectives of land, capital and labor. From the perspective of sustainable development, urban parks and green areas were taken as environmental indicators in the output index of construction land-use efficiency by referring to Tang et al. (2021)’s study in Yangtze River Delta. In the selection of specific indexes, we refer to the indexes representing each category in the studies of Lv et al. (2019), Wei et al. (2021) and Feng et al. (2022). The exact data will be described in Measurement Model part. Following the logic of sustainable urban development, the construction land-use efficiency evaluation index of this paper is shown as follows:

- λ T*arget layer: Construction land-use efficiency*
- λ Criterion layer:
  1) Input index layer: Urban construction land area; Urban total fixed-asset investment; Urban non-agricultural (second, third) practitioners
  2) Output index layer: Urban non-agricultural (second, third) output value; City revenue; Urban park and green area

3.2 Tobit model approach

The efficiency of urban construction land use is measured with DEA as the dependent variable and their values all fall in the (0, 1) interval. Ordinary least squares (OLS) is one of the most widely employed statistical methods to analyze the linear relationship between variables. An important assumption of OLS is that the expected value of residuals is 0. Due to the particularity of the data, this study may not meet the presumptions of OLS and its estimators might be biased. Tobit model proposed by Tobin (1958) is suitable for solving finite-dependent variable problems. The Tobit model adopts the maximum likelihood estimation method to estimate parameters in the model. This paper adopts the Tobit model to explore the impact of urban external economic connections, information exchange and social networks on urban construction land-use efficiency. The authors follow several researchers’ work to select control variables (Conrad et al., 2020; Dagar et al., 2021; Wang et al., 2021; Rehman et al., 2022; Xue et al., 2022). Please refer to Supplementary Appendix S2 for the establishment of the Tobit regression model.

The proportion of total passenger volume, the proportion of Internet users and the proportion of public management and social organization employees are selected to measure the three variables. In order to measure the location characteristics of the city, two dummy variables, whether a river port city or an open economic city, are defined. The explanation of variables and data sources of the Tobit model are shown in Table 1.

3.3 Data sources

By referring to previous works (Xu et al., 2019; Chou et al., 2020; Huang et al., 2022; Ma et al., 2022), the corresponding data of the selected indexes was manually collected from statistical yearbooks published by the Urban Social and Economic Survey Department of the National Bureau of Statistics in China. In particular, the data was collected from China City Statistical Yearbook (2004–2016), China Urban Construction Statistical Yearbook (2004–2016) and the statistical yearbook of 25 prefecture-level cities (2004–2016). These yearbooks recorded urban economic development data and resource utilization related data such as the level of public facilities, urban water supply, urban water conservation, urban energy consumption.

4 Results and discussion

4.1 Static land use efficiency results and analysis

Based on the C2R model, DEAP2.1 software was used to calculate the land use comprehensive technical efficiency value

TABLE 1 Tobit regression model variables.

Var	Symbol	Explanation	Unit	Data sources
dis	dis	distance from the port of YangShan	100 km	Baidu map ranging tool
X	landchange	the rate of change of urban built-up area	%	China Urban Construction Statistical Yearbook
	urbanization	non-agricultural population of district/registered population of the district	%	Statistical yearbook of provinces and cities
	inv	fixed investments/GDP	%	China City Statistical Yearbook
	gov	government expenditures/GDP	%	China City Statistical Yearbook
	edu	number of higher learning institutions		China City Statistical Yearbook
	water	per capita water supply	m^3/person	China Urban Construction Statistical Yearbook
	energy	per capita energy supply	Kwh/ person	China Urban Construction Statistical Yearbook
	tsi	the upgrading of industrial structure (output value of tertiary industry/output value of secondary industry)	%	China City Statistical Yearbook
	ties	external social association (total urban passenger volume/non-agricultural population of district)	%	China City Statistical Yearbook
	net	the transmission of information (internet users/non-agricultural population of district)	%	China City Statistical Yearbook
	orgs	degree of social network organization development (number of employees in public administration and social organizations in the jurisdiction/number of employees in institutions at the end of the year)	%	China City Statistical Yearbook
Z	riverport	whether a river port city		"BBS summit of the first Chinese port city mayors' conference"
	open	whether an open city		List of special economic zones

(crste) for 25 prefecture-level cities in the Yangtze River Delta from the 2004–2016, and then the BC2 model was used to calculate the land use pure technical efficiency value (vrste). Finally, the scale efficiency value (scale) is obtained, that is, the quotient of the comprehensive technical efficiency value and the pure technical efficiency value (Table 2). According to the data results in Table 2, we can find some rules and characteristics of each city's land use comprehensive technical efficiency (crste) value. Based on this, we divide the city clusters in the Yangtze River Delta into four types: advantage-led (the crste stays at a high level), comprehensive lag (the crste stays at a low level), optimization and promotion (the crste increases continuously), and degeneration (the crste decreases continuously).

Type 1: Advantage-led. The crste value of each city in this type stays at a high level, which is 1.00 from 2014 to 2016. The comprehensive technical efficiency of five cities including Nanjing, Wuxi, Suzhou, Yangzhou, Hangzhou and Jinhua has minor changes in 12 years. It has been in the effective state of the DEA production frontier. From the perspective of factor matching, these five cities have reached the forefront in terms of factor matching and scale reporting efficiency; Type 2: Comprehensive lag. The crste value of each city in this type stays at a low level, which is below 0.80 from 2014 to 2016. The four cities of Taizhou, Anqing, Chuzhou, and Xuancheng have always had a low level of comprehensive technical efficiency, and they have not reached the frontier of effective production; specifically, these four cities are unreasonable in terms of factor matching, but the scale returns are similar. It is in an ascending state, which shows that what restricts the development of the local economy is the lag in technical efficiency; Type 3: Optimization and promotion. The crste value of each city in this type continuously increases from 2014 to 2016. The four cities including Changzhou, Zhoushan, Jiaxing, and Taizhou have continuously improved their already leading comprehensive technical level. In terms of scale returns, they have also been in the stage of increasing returns to scale. It shows that these areas not only have a reasonable combination of factors, but also have advanced production technology to ensure that the factor inputs get the maximum output; Type 4: Degeneration. The crste value of each city in this type continuously decreases from 2014 to 2016. Shaoxing, Hefei, Ma'anshan, Chizhou and other four cities can maintain a leading position in their areas, but in recent years, they have been steadily declining. These four cities are constantly unbalanced in factor matching, and their scale returns are also declining, indicating that these areas have severe factor outflows of factor resources and have not undertaken effective technologies to support factor inputs in their regions.

4.2 Dynamic land use efficiency results and analysis

To further analyze the characteristics of changes in construction land use efficiency through the decomposition of

TABLE 2 Decomposition of land use efficiency of urban agglomerations 2014–2016.

Year	2014			2015			2016		
City	Crste	Vrste	Scale	Crste	Vrste	Scale	Crste	Vrste	Scale
Nanjing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wuxi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Changzhou	0.874	0.900	0.972	0.909	0.947	0.960	0.913	0.943	0.968
Suzhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Nantong	0.883	0.887	0.996	0.874	0.883	0.990	0.885	0.886	0.999
Yancheng	1.000	1.000	1.000	0.982	0.983	0.999	0.891	0.918	0.971
Yangzhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhenjiang	0.936	0.961	0.974	0.916	0.961	0.954	0.905	0.951	0.952
Taizhou	0.743	0.860	0.864	0.755	0.853	0.885	0.757	0.840	0.900
Hangzhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningbo	0.905	0.931	0.972	0.989	0.991	0.997	0.902	0.910	0.991
Jiaxing	0.887	0.891	0.996	0.877	0.885	0.991	0.969	0.991	0.977
Huzhou	0.932	0.999	0.933	0.891	0.966	0.923	0.919	0.971	0.946
Shaoxing	0.843	0.918	0.919	0.753	0.821	0.917	0.744	0.788	0.945
Jinhua	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhoushan	0.988	1.000	0.988	0.871	1.000	0.871	0.918	1.000	0.918
Taizhou	0.825	0.947	0.871	0.832	0.886	0.940	0.866	0.906	0.955
Hefei	0.932	0.934	0.999	0.789	0.797	0.990	0.821	0.826	0.994
Wuhu	0.792	0.809	0.979	0.752	0.800	0.940	0.750	0.791	0.947
Maanshan	0.875	0.883	0.991	0.991	1.000	0.991	0.798	0.856	0.933
Tongling	0.887	1.000	0.887	0.622	0.911	0.683	0.751	0.910	0.826
Anqing	0.649	0.698	0.929	0.603	0.706	0.854	0.621	0.688	0.902
Chuzhou	0.446	0.622	0.718	0.398	0.579	0.687	0.594	0.697	0.853
Chizhou	0.973	1.000	0.973	0.892	1.000	0.892	0.873	1.000	0.873
Xuancheng	0.718	0.984	0.730	0.764	0.879	0.869	0.776	0.984	0.788

total factor productivity (TFP), it is necessary to use the Malmquist index method to deconstruct the relevant data dynamically. As shown in Table 3, the average total output productivity level of the Yangtze River Delta urban agglomeration is 1.014, the overall trend is rising, and the period of large fluctuations in the middle is 2007–2009. During the year, this greater degree of recession should be related to the spreading of the financial crisis.

From the perspective of technical efficiency change (TEC), the periods of recession occurred between 2007–2008 and 2013–2015. Furthermore, we can find that the technical levels corresponding to the two periods have appeared a decrease by about 1.4%. The scale efficiency between 2007 and 2008 is rising. Although the scale efficiency between 2013 and 2015 is decreasing, the disease is not obvious, and the decline is 0.6%. The main factor is the obstruction of the technical level.

From Table 3, we can find that from 2004 to 2016, only Yangzhou, Zhenjiang, Taizhou, Tongling, Anqing, Chuzhou, and Chizhou showed negative growth in total factor productivity TFP, while the rest all increased to varying degrees. Generally, the TFP growth rate is also larger; similarly, the area farther away from Shanghai is also a region with negative growth in technical efficiency and a larger decline.

4.3 Temporal-spatial efficiency of urban land use in the Yangtze river delta

Urban construction land-use efficiency of the 25 prefecture-level cities from 2004 to 2016 was analyzed by DEAP2.1 and the results are shown in Table 4. In order to visualize the temporal-spatial efficiency of urban land use in the Yangtze River Delta urban agglomeration, ArcGIS 10.6 is used to map the spatial distribution (Figure 1). It can be concluded that the urban construction land-use efficiency reveals three characteristics during the study period:

1) The values of construction land-use efficiency are generally high. Most cities are above 0.7. Construction land-use efficiency in Chuzhou and Xuancheng is the lowest. In

10.3389/fenvs.2022.1039028

TABLE 3 Period TFP index and Malmquist index of 25 cities in Yangtze River Delta.

Year/City	TEC	TC	PTEC	SEC	TFPC
TFP index					
2004–2005	1.002	1.005	1.006	0.996	1.007
2005–2006	0.935	1.092	0.945	0.989	1.021
2006–2007	0.988	1.037	1.009	0.979	1.025
2007–2008	0.987	0.962	0.994	0.993	0.950
2008–2009	0.987	1.012	0.996	0.992	0.999
2009–2010	1.035	1.008	1.027	1.008	1.044
2010–2011	1.020	1.029	0.994	1.027	1.050
2011–2012	1.027	0.985	1.013	1.014	1.012
2012–2013	1.001	1.008	1.005	0.996	1.010
2013–2014	0.987	1.012	0.998	0.990	1.000
2014–2015	0.966	1.060	0.982	0.984	1.024
2015–2016	1.019	1.010	1.002	1.016	1.029
Malmquist index					
City	TEC	TC	PTEC	SEC	TFPC
Nanjing	1.000	1.010	1.000	1.000	1.010
Wuxi	1.001	1.029	1.001	1.000	1.031
Changzhou	0.992	1.040	0.995	0.997	1.032
Suzhou	1.000	1.043	1.000	1.000	1.043
Nantong	0.990	1.038	0.990	1.000	1.028
Yancheng	1.010	1.021	1.012	0.998	1.030
Yangzhou	1.001	0.993	1.000	1.001	0.993
Zhenjiang	0.992	1.006	0.996	0.996	0.997
Taizhou	0.990	1.018	0.997	0.993	1.008
Hangzhou	1.000	1.035	1.000	1.000	1.035
Ningbo	0.991	1.049	0.992	0.999	1.040
Jiaxing	1.028	1.022	1.020	1.008	1.050
Huzhou	1.029	1.005	1.031	0.999	1.035
Shaoxing	0.988	1.024	0.991	0.997	1.011
Jinhua	1.012	1.018	1.010	1.002	1.031
Zhoushan	1.023	1.026	1.011	1.012	1.050
Taizhou	0.996	0.996	0.993	1.003	0.992
Hefei	0.993	1.031	0.994	1.000	1.024
Wuhu	0.986	1.025	0.989	0.997	1.011
Maanshan	0.983	1.046	0.987	0.996	1.029
Tongling	0.976	1.007	0.992	0.984	0.983
Anqing	0.961	0.997	0.969	0.991	0.959
Chuzhou	0.958	0.990	0.970	0.987	0.948
Chizhou	0.989	0.981	1.000	0.989	0.970
Xuancheng	1.012	1.001	0.999	1.013	1.012

particular, the efficiency of Chuzhou was 1.000 in 2004 and dropped sharply from 0.750 to 0.545 during 2006 and 2007. It can be found from the input indicators of Chuzhou increased significantly from 2006 to 2007, but the output did not increase as much correspondingly. The efficiency of Xuancheng has been low but has improved since 2012.

2) The efficiency of the target cities fluctuated between 2004 and 2016. In the 2008 global financial crisis, China launched the "Four-trillion" bailout plan in November of that year, and the program lasted until 2011. The four trillion RMB was intensively invested in government-subsidized housing and infrastructure projects. The construction land-use efficiency was improved in the short term. However, some local governments continued to excessively expand urban construction land and raise funds for urban construction projects. Since 2013, the urban construction land-use efficiency has begun to decline.
3) The urban construction land-use efficiency of the 25 cities is higher in the south and lower in the north; higher in the east and lower in the west. The efficiency of Jiangsu and Zhejiang province is relatively high, while that of Anhui province is comparatively low. The average efficiency of the 9 prefecture-level cities in Jiangsu province from 2004 to 2016 was 0.917, and that of the 8 prefecture-level cities in Zhejiang province was 0.916, while that of the 8 prefecture-level cities in Anhui province was only 0.780.

4.4 Deconstructing the efficiency of urban construction land use

It can be found that the urban construction land-use efficiency and the distance to YangShan are simulated by cubic curve and the R^2 ($R^2 = 0.2789$), which indicates that geographical location explains the construction land-use efficiency to a certain extend.

Then we make the data regression of urban construction land-use efficiency and the results are displayed in Supplementary Appendix S3. According to the regression results, dis and dis^2 are significant at the 10% level, dis^3 is significant at the 5% significant level among all influencing factors of urban construction land-use efficiency. It implies a nonlinear "∽" relationship between the urban construction land-use efficiency of 25 prefecture-level cities in the Yangtze River Delta urban agglomeration and the distance to the YangShan Port.

Moreover, it is also believed that the relationship between population density and land use in the built-up area shows a U-shaped curve. We estimate that the farthest effective radiation range of Shanghai to the Yangtze River Delta is 361.5 km, which can reach the Quzhou, Lishui and Taizhou loops in the Zhejiang province. Huangshan, Tongling, Wuhu and Ma'anshan can be reached within the provincial administrative area, and within the scope of Jiangsu Province are Zhenjiang, Yangzhou and Taizhou.

In order to clarify the specific factors affecting the utilization efficiency of construction land, we conducted attribution analysis on the main influencing factors from three angles: comprehensive technical efficiency level, pure technical efficiency level and scale efficiency.

TABLE 4 Urban construction land-use efficiency of the 25 prefecture-level cities in the Yangtze River Delta urban agglomeration from 2004 to 2016.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Avg
Nanjing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wuxi	0.985	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999
Changzhou	1.000	1.000	0.871	0.82	0.808	0.769	0.837	0.852	0.861	0.844	0.874	0.909	0.913	0.874
Suzhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Nantong	1.000	1.000	1.000	1.000	0.716	0.679	0.661	0.67	0.8	0.817	0.883	0.874	0.885	0.845
Yancheng	0.795	0.757	0.619	0.628	0.674	0.745	0.818	0.91	1.000	1.000	1.000	0.982	0.891	0.832
Yangzhou	0.989	1.000	0.957	0.958	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.993
Zhenjiang	1.000	1.000	0.919	1.000	0.973	0.912	0.854	0.927	0.909	0.926	0.936	0.916	0.905	0.937
TaiZhou	0.85	0.858	0.75	0.677	0.791	0.815	0.785	0.763	0.822	0.722	0.743	0.755	0.757	0.776
Hangzhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningbo	1.000	1.000	0.864	0.892	0.882	0.86	0.972	1.000	1.000	1.000	0.905	0.989	0.902	0.944
Jiaxing	0.695	0.724	0.744	0.68	0.715	0.681	0.776	0.811	0.903	0.903	0.887	0.877	0.969	0.797
Huzhou	0.649	0.649	0.632	0.823	0.802	0.867	0.895	0.907	1.000	0.953	0.932	0.891	0.919	0.84
Shaoxing	0.865	0.953	0.927	0.939	1.000	1.000	1.000	1.000	1.000	0.911	0.843	0.753	0.744	0.918
Jinhua	0.868	0.929	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.984
Zhoushan	0.697	0.718	0.886	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.988	0.871	0.918	0.929
Taizhou	0.908	0.997	0.934	0.879	0.919	0.918	0.973	0.999	0.97	0.908	0.825	0.832	0.866	0.918
Hefei	0.889	0.779	0.6	0.733	0.74	0.86	0.869	0.864	0.749	0.787	0.932	0.789	0.821	0.801
Wuhu	0.886	0.821	0.72	0.647	0.604	0.664	0.733	0.816	0.797	0.801	0.792	0.752	0.75	0.753
Maanshan	0.981	0.978	0.97	1.000	1.000	1.000	1.000	0.855	0.856	1.000	0.875	0.991	0.798	0.946
Tongling	1.000	1.000	1.000	1.000	0.968	0.838	0.903	0.997	0.986	0.941	0.887	0.622	0.751	0.915
Anqing	1.000	0.987	0.778	0.695	0.655	0.562	0.518	0.556	0.555	0.612	0.649	0.603	0.621	0.676
Chuzhou	1.000	0.948	0.75	0.545	0.448	0.372	0.416	0.434	0.47	0.471	0.446	0.398	0.594	0.561
Chizhou	1.000	1.000	1.000	1.000	0.977	1.000	0.943	1.000	0.948	0.974	0.973	0.892	0.873	0.968
Xuancheng	0.676	0.685	0.527	0.428	0.438	0.409	0.562	0.551	0.753	0.804	0.718	0.764	0.776	0.622
Avg	0.909	0.911	0.858	0.854	0.844	0.838	0.861	0.876	0.895	0.895	0.884	0.858	0.866	0.873

1) The level of comprehensive technical efficiency is highly negatively correlated with the geographical location of the city and insufficiently correlated with scale efficiency. Explain that in terms of the production efficiency related to the input and output of factors, the adoption of the latest technological achievements also has a progressive process. Generally, the closer to the Shanghai port area, the higher the production efficiency of the elements, but the allocation and utilization efficiency of the elements have no strong correlation between them.
2) The factors that affect the level of pure technical efficiency are mainly the government, built-up area, investment level, external social linkages and social organization factors, indicating that the organization and allocation of urban construction land elements in the Yangtze River Delta area are more subject to government policy regulation and social The impact of capital, in other words, the dominant position of the market mechanism in the allocation of construction land has not been fully exerted.
3) The leading factors that determine the level of efficiency of construction land scale are government expenditure, urbanization level, investment level, industrial structure optimization and regional education level. Therefore, we believe that the scale efficiency of urban construction land use in the Yangtze River Delta region is more derived from the improvement of labor quality, the development intensity of capital-oriented development, the adjustment and optimization of industrial agglomeration, and the government's policy dividend.

5 Conclusion

The paper adopts DEA-Malmquist and Tobit model to evaluate the construction land-use efficiency of the Yangtze River Delta urban agglomeration and then uses the Tobit model to explore the influencing factors of land use efficiency. The following conclusions can be drawn from the results and discussions.

From 2004 to 2016, the urban construction land-use efficiency of the 25 prefecture-level cities in the Yangtze River Delta urban agglomeration fluctuated, and only Nanjing, Suzhou

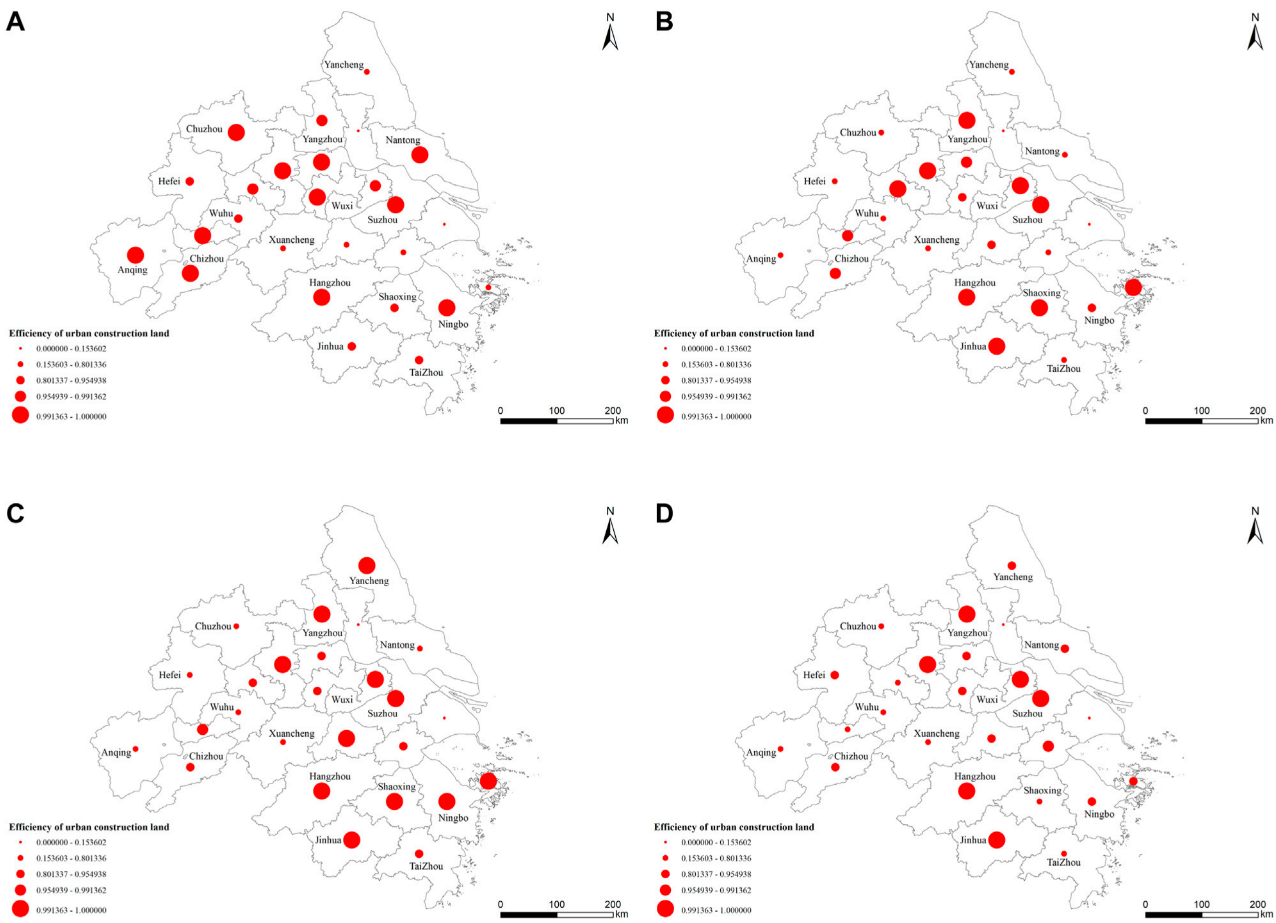

FIGURE 1
Spatial distribution of urban construction land-use efficiency from **(A)** 2004, **(B)** 2008, **(C)** 2012, **(D)** 2016.

and Hangzhou had a constant efficiency value of 1.000. The average efficiency of Jiangsu province and Zhejiang province is significantly higher than Anhui province.

Geographical location impacts the urban construction land-use efficiency. Distance to the port of YangShan reveals a nonlinear "∽" relationship to the land-use efficiency of the 25 cities, The effective radiation distance of Shanghai to the Yangtze River Delta is 361.5 km.

Capital expansion, the improvement of labor quality and industrial agglomeration are currently the main driving factors for the improvement of land utilization efficiency. In the future, more attention will be paid to the role of market resource allocation and scientific and technological progress to improve efficiency. Excessive urban expansion and investment negatively influence the urban construction land-use efficiency. "Land finance" might work for a certain period, but its benefits for land-use efficiency would not last long.

Based on the above conclusions, the following policy suggestions can be put forward:

1) More attention should be paid to the intensive use of land through proper planning and management to improve the urban construction land-use efficiency in Anhui Province. Need to integrate more into the integrated development of the Yangtze River Delta, especially in terms of technical efficiency improvement and construction land system design. It would be less beneficial for the government to overly depend on urban expansion and investment in fixed assets to promote economic development. Compact and highly efficient use of urban construction land will benefit the urban development in the long run.

2) Although the distance to the port, cannot be changed, there is still room for improvement in economic ties with port cities. As ports are the hubs of trade and commerce, the accessibility and economic ties to major ports are significant for most cities. Therefore, transportation integration is crucial to

the economic and social integration of the Yangtze River Delta region. When planning the construction of the intercity railway, the accessibility to major ports should be considered as a key issue to improve land-use efficiency.

3) Land use efficiency will be probably improved through soft power building such as a faster urbanization process, promoting education, optimizing the industrial structure and strengthening the social connections with other cities. First, in terms of the urbanization process, urbanization should be promoted in coordination with social and economic development. It would be less rewarding for the government to focus on the urbanization rate, rather than on the promotion of the urban way of life with quality. As for education, the development of science, education and culture is of no less importance to economic development. In the Romer-Lucas model, the long-term economic growth is achieved by proportionately increasing returns, whose source is identified as knowledge. The industrial structure can be adjusted in line with the industrial agglomeration of central port cities to maximize the benefits of agglomerations. In the same agglomeration, peripheral cities take over the industries transferred from the central cities so as to synergize the regional industries. At the same time, the upgrading of industrial structure injects dynamics into the urban economy of the urban agglomeration as well. In terms of external connections and exchanges, the circulation of materials and talents between cities should be strengthened, and basic transportation infrastructure should be provided for the circulation of production elements among cities in the same urban agglomeration.

There are also some limitations in our study. First, due to data sources limitations, we only study the land use efficiency between 2004 and 2016. Further, we will extend the research period to the present. Second, we only consider 25 representative prefecture-level cities in Yangtze River Delta urban agglomeration. More small cities like Yixing, Haimen can be taken into consideration in the future. Third, the selection of variables in the paper is subject to the statistical yearbook. In the future, we can use data crawling technology like Python to obtain more dimensional data for supplementary research.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by WW, XQ, QL. The first draft of the manuscript was written by WW, QL, QZ, YC and XC, and QL commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1039028/full#supplementary-material

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