

*Original Research*

# An Empirical Study on Ecological Efficiency and Influencing Factors of Industrial Enterprises in Fujian Province, China

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## Abstract

Statistical data related to industrial enterprises from 2011 to 2016 in Fujian Province of China show that the ecological efficiency of industrial enterprises has some temporal and spatial distribution characteristics. In general, ecological efficiency was increasing year by year with great differences within the regions, and the difference increase with time. The efficiency in the eastern region was higher than that in other areas. Based on considering spatial weights and combing the spatial econometric model, this paper studied the influencing factors of ecological efficiency of industrial enterprises, and draws conclusions that population density, per-capita GDP, the proportion of industrial output value and the comprehensive utilization rate of industrial solid waste have a significant positive impact on the ecological efficiency of industrial enterprises. In addition, the ratio of value of import and export goods to GDP and the ratio of expenditure on R&D to general public expenditures have a significant negative impact on the ecological efficiency of industrial enterprises, then put forward some relevant countermeasures and suggestions.

**Keywords:** industrial enterprises; ecological efficiency; spatial econometric; super-efficiency DEA

## Introduction

The ecological environment is the foundation on which human beings rely for their survival, and an important barrier for healthy economic and societal development. Industry plays a leading role in the national economy, and its output value occupies an

important position in the national economy. Since 2002, the proportion of industrial output value to GDP has exceeded 40% every year in China. In the process of development, industrial enterprises bear the main source of GDP and make significant contributions to the development of the national economy. At the same time, it will also bring an adverse impact on the ecological environment.

Transforming the mode of economic growth, developing circular economy and building a resource-conserving and environmentally friendly society are China's long-term development goals. Ecological

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civilization and sustainable development have become one of the focuses of China's future economic development. As an important tool for measuring the benefits of ecological input and ecological output, eco-efficiency has become an important indicator to evaluate synergy among the economy, resources and environment. Fujian Province is located on the southeast coast of China (115°40'-120°50', 23°20'-28°40'N), as the first experimental zone of ecological civilization in the country and the "core area" of the 21<sup>st</sup>-century Maritime Silk Road, it naturally has to make its due contributions to improving ecological efficiency. However, although Fujian's eco-environmental quality has its advantages over other inland provinces in China, in recent years, in the process of promoting industrialization, urbanization and agricultural modernization, the consumption of fossil energy is still increasing. If the government does not attach importance to the transformation of this method of energy consumption, it is difficult to maintain the superiority of this ecological environment in Fujian. Therefore, how to measure the ecological efficiency of industrial enterprises and ensure sustainability of the ecological environment has become one of the key issues in today's research.

Schaltegger et al. (1990), a German scholar, put forward the concept of eco-efficiency for the first time, pointing out that eco-efficiency was used to assess the ratio efficiency of economic activity output and resources and the environment [1]. In 1992, the World Business Council for Sustainable Development (WBCSD) formally put forward the definition of eco-efficiency, believing that ecological efficiency refers to the value and environmental load of environmental efficiency products or services, which is the ratio of input to output [2]. This definition was first introduced in China in 1995. Subsequently, WBCSD (2000) noted that the relationship between human impacts on the environment and the carrying capacity of the planet could be measured through eco-efficiency, focusing on the maximization of goods and services and value added [3]. At present, the definition put forward by WBCSD in 2000, that is, ecological efficiency is equal to the ratio of economic value added to environmental impact, is accepted internationally. Eco-efficiency provides an important theoretical basis for enterprises to realize the "win-win" of environmental and economic benefits.

With the promotion of ecological civilization construction, the research on eco-efficiency of enterprise is also increasing, from the initial micro-level application of industry, such as enterprises, products and industries, it has gradually expanded to macro-level research on a regional level. Zhang et al. (2013) calculated the optimal relative industrial eco-efficiency of China's regional industry under the environmental pressure index, and analyzed the influencing factors of industrial eco-efficiency by the Tobit model. It is concluded that the industrial eco-efficiency of China's provinces is generally low, and the regional differences are large [4].

Pan et al. (2014) evaluated the industrial eco-efficiency of central and eastern provinces of China from 2005 to 2010, and confirmed that the industrial eco-efficiency of six central provinces was lower than that of the eastern provinces, and even lower than the national average. It showed that the industrial development of the central provinces is still at the cost of resource consumption and environmental impact [5]. Zhou et al. (2015) analyzed the eco-efficiency from the microcosmic level of enterprises, and tested the eco-efficiency of manufacturing export enterprises with the survey data of Chinese manufacturing enterprises published by the World Bank in 2013 [6]. Tian et al. (2015) analyzed the ecological efficiency improvement and optimization strategy of low-carbon mergers and acquisitions for the first time [7]. Koskela (2015) discussed the measurement of eco-efficiency in the Finnish forest industry from three perspectives [8]. Xie et al. (2016) used the grey comprehensive evaluation model based on the center point triangle whitening weight function to study the eco-efficiency of a specific iron and steel enterprise, which belongs to the micro-level research of the enterprise [9]. Using data envelopment analysis (DEA) and the Malmquist productivity index model, Kong (2016) selected 40 representative large and medium-sized iron and steel enterprises in China as the evaluation unit, and confirmed that the eco-efficiency of Chinese iron and steel enterprises was on the rise as a whole. The improvement of eco-efficiency is mainly dependent on technological progress, while economies of scale are not reflected [10]. Zhao et al. (2016) believed that according to the ecological efficiency of industrial enterprises, the 30 provinces, autonomous regions and municipalities in China can be divided into six types: relatively high efficiency, relatively low efficiency, high efficiency and high input, high efficiency and low input, low efficiency and high input, and low efficiency and low input. Regions should take measures to improve eco-efficiency according to their own characteristics [11]. At the meso-level, eco-efficiency in industrial water-service systems were assessed using new methodology that was developed by authors [12]. Gao (2017) confirmed that most economically developed regions have higher ecological efficiency values, while resource-rich regions rely excessively on resource consumption for economic development, but their ecological efficiency values were not high [13]. Moreover, Carvalho et al. (2017) presented an eco-efficiency perspective to propose a model to help managers identify the best set of green and lean supply chain management practices to improve eco-efficiency [14]. In addition, the currently existing literature is also concerned with environmentally friendly consumption and production, and resource efficiency in industrialized and emerging countries, which aims at assessing environmental and economic sustainability [15, 16].

Regarding the influencing factors of ecological efficiency, Zhang et al. (2013) confirmed that per capita

GDP and geographical location had positive effects on the improvement of eco-efficiency [4]. Pan et al. (2014) believed that industrial structure, utilization of foreign capital, investment in research and development, and investment in pollution control had significant influence on the source reduction efficiency and end treatment efficiency of the ecological efficiency of industrial enterprises [5]. Taking the ecological efficiency of industrial enterprises in 31 provinces, autonomous regions and municipalities directly under the central government in China from 2008 to 2011 as an example, Gao (2017) thought that the ecological efficiency of industrial enterprises is influenced by environmental variables such as industrial pollutant control investment, government environmental protection policy, light and heavy industrial structure, and R & D investment of enterprise [13]. Studies such as Wang et al. (2017) have confirmed that population density, per capita GDP, industrial structure and environmental regulation of the old industrial base in northeastern China have a promoting effect on ecological efficiency, while the opening to the outside world and the level of science and technology have hindered the improvement of eco-efficiency, and the above-mentioned influencing factors are also important reasons for the formation of regional differences in eco-efficiency of the old industrial base in northeastern China [17].

To sum up, the research results of eco-efficiency of industrial enterprises are relatively few, and the research content has gradually expanded from the micro-level of enterprises, products, and industries to the macro-level of regions, which has important reference significance for exploring the factors that affect the eco-efficiency of industrial enterprises and improving eco-efficiency in Fujian Province. However, academia generally believes that there are spatial differences in the eco-efficiency of industrial enterprises. Due to the differences in resource endowment, industrial structure and economic development level among different regions, the path of social and economic development is different. Then the contribution to eco-efficiency is also very different, so the study of a specific region is particularly critical. In addition, the existing literature mainly used the DEA model to measure eco-efficiency [18-21], and rarely used the super-efficiency DEA model and spatial econometric model to scientifically and effectively analyze the influencing factors of eco-efficiency scientifically and effectively. Therefore, based on the data of industrial enterprises from 2011 to 2016 in Fujian Province, this study analyzed the correlation between the dynamic evolution of eco-efficiency of industrial enterprises and its spatial, and used the super-efficiency DEA model and spatial econometric model to discuss the influencing factors of eco-efficiency, with a view to promoting the improvement of the ecological efficiency of Fujian's industrial enterprises and strengthening the construction of ecological civilization.

## Methods

### Super-Efficiency DEA Model

In efficiency measurement, the data envelopment analysis (DEA) model proposed by Charnes et al. (1978) has become the mainstream measurement tool [22]. The model uses nonparametric methods to evaluate the relative effectiveness between multi-input and multi-output decision making units (DMU) in complex systems. The first basic model was called the CCR model, which was initially proposed by Charnes, Cooper and Rhodes in 1978 [22]. The CCR model assumes constant return to scale (CRS), which may not be true for some applications. To address this issue, researchers have implemented variable returns to scale (VRS) into the original DEA model, that is, the DEA model that implemented variable return to scale (VRS) was known as the BCC model (Banker, Charnes and Cooper, 1984) [23]. At the same time, DEA also includes input-oriented and output-oriented models in order to avoid the efficiency value of DEA being between 0 and 1, which makes it impossible for many decision-making units to compare their efficiencies when they are relatively effective. The super-efficiency DEA model is a model for the above shortcomings, and its mathematical expression is as follows:

$$\begin{cases} \min \theta \\ s. t. \sum_{j=1, j \neq m}^n x_j \lambda_j + s^- = \theta x_m \\ \sum_{j=1, j \neq m}^n y_j \lambda_j - s^+ = y_m \\ \lambda_j \geq 0, j = 1, 2, \dots, n \\ s^- \geq 0, s^+ \geq 0 \end{cases} \quad (1)$$

...where  $\theta$  denotes the super-efficiency value of each DMU, which reflects the relative effectiveness of the input-output efficiency.  $\lambda$  represents the dual variables that identify the benchmarks for inefficient units.  $s^-$  represents input slack variables, and  $s^+$  represents output slack variables; and  $x_j$  and  $y_j$  denote input and output indices of DMUs, respectively.

Through the above model, the relative value of eco-efficiency of industrial enterprises can be effectively measured.

### Spatial Autocorrelation

As a new branch of discipline, spatial metrology first began in the 1970s and 1980s. According to Anselin (1988), the basic content of spatial econometrics was to consider the spatial effect of economic variables in the econometric model, and to carry out a series of corresponding econometric model methods of model setting, estimation, testing and forecasting [24]. Therefore, it is necessary to study the spatial distribution of variables and consider the weight of space

in the economic model when we study the economic variables with geographical attributes.

Spatial autocorrelation reflects the agglomeration state of variables in spatial distribution. Global spatial autocorrelation is represented by Moran's I. Spatial weight matrix  $W$  is usually defined before spatial autocorrelation analysis. The spatial weight matrix  $W$  is defined as follows:

$$W = \begin{pmatrix} W_{11} & W_{12} & \dots & W_{1j} & \dots & W_{1n} \\ W_{21} & W_{22} & \dots & W_{2j} & \dots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ W_{i1} & W_{i2} & \dots & W_{ij} & \dots & W_{in} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \dots & W_{nj} & \dots & W_{nn} \end{pmatrix} \quad (2)$$

...where  $W_{ij}$  indicates the proximity relationship between region  $i$  and region  $j$ . When region  $i$  and region  $j$  are adjacent to each other, the value is 1; otherwise, the value is 0.

Moran's  $I$ , which measures global spatial autocorrelation, is defined as:

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n W_{ij}} \times \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_{i=1}^n (X_i - \bar{X})^2} \quad (3)$$

...where  $n$  denotes the number of regions,  $W_{ij}$  represents the proximity relationship between region  $i$  and region  $j$ ,  $X_i$  indicates the values of a particular region, and  $\bar{X}$  denotes the average value of a particular region.

If  $I$  is less than 0, it means negative correlation; when  $I$  is equal to 0, it means no correlation; and if  $I$  is greater than 0, it indicates positive correlation. The nearer  $I$  is to -1, the less centralized the distribution, and the closer  $I$  is to 1, the more centralized the distribution.

### Spatial Measurement Model

There is a certain correlation between regional economic development and geographical space, and economic development reflects some characteristics of geographical space. Traditional econometric models ignored the impact of geographical regions on economic development, and cannot objectively reflect the influence of geographical space on economic development. The adoption of the spatial econometric model can basically solve this problem. It considers that a certain geographical economic phenomenon of a spatial unit or a certain attribute value has spatial dependence or spatial correlation with the adjacent spatial unit, which is consistent with the fact of social development. Therefore, this paper abandoned the traditional econometric model and used the spatial econometric model to measure and analyze. The basic models of spatial econometric model mainly include the spatial lag model and spatial error model. The spatial lag model indicates that the spatial dependence between the explained variables is very critical to the model, which leads to the spatial

correlation; the spatial error shows that the error terms of the model are spatially correlated.

The spatial hysteresis model can be represented as:

$$Y = \rho WY + X\beta + \varepsilon, \varepsilon \sim N[0, \sigma^2] \quad (4)$$

...where  $Y$  denotes the explained variable,  $X$  is the explanatory variable matrix,  $\rho$  is the spatial effect coefficient.  $\varepsilon$  is an error vector and obeys a normal distribution where the mean is zero and the variance is  $\sigma^2$ .  $\beta$  is the parameter vector and  $W$  is the spatial matrix, which is specifically expressed as follows:

$$W = \begin{pmatrix} 0 & W_{12} & \dots & W_{1j} & \dots & W_{1N} \\ W_{21} & 0 & \dots & W_{2j} & \dots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ W_{i1} & W_{i2} & \dots & W_{ij} & \dots & W_{iN} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \dots & W_{Nj} & \dots & 0 \end{pmatrix} \quad (5)$$

...where  $W_{ij}$  describes the correlation between the variables explained by  $j$ -th and  $i$ -th.

The spatial error model can be expressed as:

$$Y = X\beta + \varepsilon, \varepsilon = \lambda W\varepsilon + \mu, \mu \sim N[0, \sigma^2] \quad (6)$$

...where  $\lambda$  is the spatial error correlation coefficient,  $\mu$  is an error vector with a spatial autocorrelation structure that obeys a normal distribution where the mean is zero and the variance is  $\sigma^2$ , and  $W_{ij}$  describes the correlation between error terms by  $j$ -th and  $i$ -th. The concrete space matrix and its related meanings are as described above.

### Variable Selection

The input indicators of eco-efficiency of industrial enterprises include environmental pollution, potential environmental pollution and energy consumption [13]. Industrial enterprises in the production process will cause damage to the ecological environment, which is mainly for environmental pollution. Environmental pollution includes the emission of pollutants and the amount of pollutants produced [5]. Due to the statistical standards, the emission of pollutants lacks sufficient index, thus it is mainly expressed as "three wastes" (waste water, waste gas and solid wastes) in industry [4].

When measuring the ecological efficiency of industrial enterprises, the main consideration is to take the non-expected output index as the input index. Environmental pollution indicators can be divided into three main categories: industrial waste gas emissions (t) ( $X_1$ ), industrial waste water emissions (10,000 t) ( $X_2$ ) and industrial solid wastes discharge (10,000 t) ( $X_3$ ). In addition, industrial enterprises need to consume a large amount of energy in production, therefore energy consumption is also used as an input indicator. Energy consumption can be expressed in terms of GDP unit energy consumption (tce/10,000 yuan) ( $X_4$ ). The output

index mainly refers to the output of the total industrial output value, expressed by the gross industrial output value above designated size (100 million yuan) ( $Y_1$ ) and the regional gross industrial production (100 million yuan) ( $Y_2$ ).

The eco-efficiency (EFF) of industrial enterprises is based on the results of the super-efficiency DEA model calculated by software MyDEA1.0.

### Influencing Factors

According to the relevant literature [4, 5, 13] and the characteristics of Fujian's development, the factors affecting the ecological efficiency of industrial enterprises are expressed as population density (person·hm<sup>2</sup>) ( $Z_1$ ), per-capita GDP (yuan) ( $Z_2$ ), the proportion of industrial output value (%) ( $Z_3$ ), the ratio of value of imports and exports goods to GDP (%) ( $Z_4$ ), the ratio of expenditure on R&D to general public expenditures (%) ( $Z_5$ ), and the comprehensive utilization rate of industrial solid wastes (%) ( $Z_6$ ).

### Data Sources

This paper selected the data of industrial enterprise and basic national economics in Fujian from 2011 to 2016. The data are mainly from the Fujian Statistical Yearbook 2012-2017, and some data are from the statistical yearbooks of various districts and cities within the province.

## Results and Discussion

### Eco-Efficiency of Industrial Enterprises

The ecological efficiencies of industrial enterprises in different districts and cities of Fujian were calculated by software MyDEA1.0 (Table 1).

Table 1 showed that the eco-efficiency of industrial enterprises in Fuzhou, Xiamen, Sanming, Quanzhou, and Nanping has maintained steady growth, indicating that with the transformation of the mode of economic development, the concept of ecological development has attached importance to these cities. Industrial enterprises in these regions pay more attention to the relationship between enterprise development and

ecological environment, and also pay attention to take the initiative to assume corporate social responsibility. In addition, although the eco-efficiency value of industrial enterprises in Putian, Zhangzhou and Ningde fluctuates occasionally, the overall trend is upward, which shows that the regions are making efforts to change the mode of economic growth and making continuous progress in policy exploration and selection. Table 1 also showed that there is a big gap in the efficiency of industrial eco-enterprises in different districts and cities. In 2016, the eco-efficiency value of Xiamen's industrial enterprises reached 3.926, which was far higher than that of 0.430 in Sanming. It can be seen that with the continuous progress of time, the efficiency gap has gradually widened. The deep-seated reasons for the differences in efficiency are worthy of further study.

In short, the eco-efficiency value of industrial enterprises in Fujian's districts and cities shows an overall upward trend, but there are differences in different regions, and the differences continue to expand over time. In fact, there are many reasons for the differences in the eco-efficiency of industrial enterprises. Judging from the original data, Fuzhou, Quanzhou and Ningde have consumed a large amount of energy, which have discharged a large amount of exhaust gas, wastewater and industrial solid waste through industrial enterprise production. At the same time, these regions used more advanced production technologies and improved production technology to produce higher output of industrial enterprises, so that the eco-efficiency value of industrial enterprises is higher than in other regions. The energy consumption and waste discharge in Putian and Xiamen were relatively small, realizing the corresponding output and achieving higher eco-efficiency of industrial enterprises. In contrast, Sanming, Zhangzhou, Nanping and Longyan failed to ensure reasonable output while consuming a large amount of energy and discharging a large amount of waste. Among them, the efficiency values of Sanming, Nanping and Longyan are even much lower than 0.600, which indicates that the input-output allocation in these areas should be further optimized to ensure further improvement of eco-efficiency values and realize the sustainable development of industrial enterprises.

Table 1. Eco-efficiency value of industrial enterprises in Fujian from 2011-2016.

Year	Fuzhou	Xiamen	Putian	Sanming	Quanzhou	Zhangzhou	Nanping	Longyan	Ningde
2011	0.537	0.687	0.579	0.152	0.599	0.353	0.137	0.249	0.620
2012	0.608	0.739	0.893	0.170	0.646	0.450	0.165	0.321	0.514
2013	0.710	0.809	0.961	0.206	0.754	0.475	0.205	0.343	0.706
2014	0.804	0.834	0.851	0.223	0.817	0.426	0.251	0.418	0.847
2015	0.879	0.933	0.995	0.295	0.884	0.661	0.290	0.413	0.833
2016	1.386	3.926	1.533	0.430	1.401	0.825	0.528	0.510	1.285

### Spatial Distribution of Eco-Efficiency in Industrial Enterprises

The matrix of spatial weight must be constructed before analyzing the spatial distribution of eco-efficiency in industrial enterprises. In this paper, a simple binary adjacency matrix was used, that is, when two regions are adjacent, the value is 1, otherwise it is 0. After the matrix of spatial weight is constructed, the spatial distribution of the eco-efficiency value of industrial enterprises is estimated by calculating Moran's I, that is, the global spatial autocorrelation of the efficiency value.

Moran's I is calculated by software GeoDa1.12. The results were as follows: Moran's I of eco-efficiency values of industrial enterprises from 2011 to 2016 are 0.080, 0.234, 0.151, 0.073, 0.181 and 0.025, respectively. From the above results, Moran's I of all years is greater than 0, which fully showed that there is a positive correlation between the eco-efficiency values in different regions, and the spatial effects of eco-efficiency should be further studied.

Through the description of an eco-efficiency quantile distribution map, it was found that there is no difference in eco-efficiency quantile distribution maps for each year from 2011 to 2016. Due to the limitation of space, this paper only takes 2016 distribution maps as an example, as shown in Fig. 1.

It can be seen from Fig. 1 that the industrial enterprises in the districts and cities in the eastern part of Fujian near the Taiwan Strait region have higher ecological efficiency from 2011 to 2016, followed by the southwest region. The northwest region has the lowest ecological efficiency.

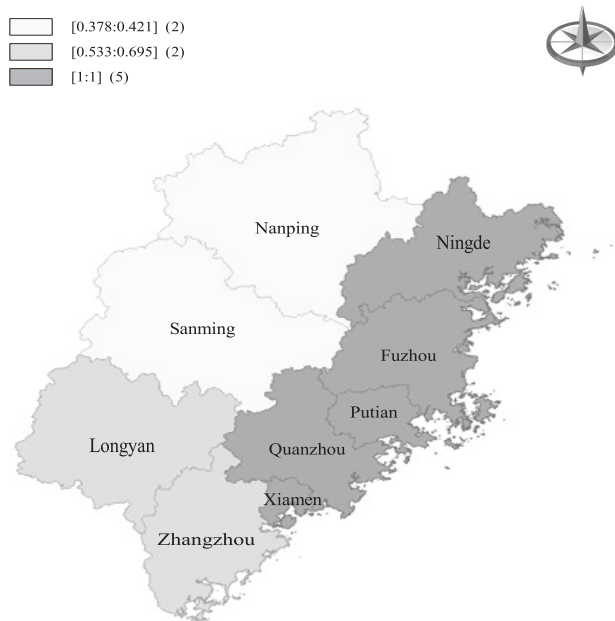


Fig. 1. Distribution map of eco-efficiency of industrial enterprises in Fujian Province.

The reason is that the eastern region has a relatively developed economy and a rich pool of talented people. It has sufficient economic foundation and technological capability to effectively control the wastes discharged from the industrial production process. To ensure that the input of resources is able to achieve a greater degree of output. The northwest area has more heavy industry, which is the old industrial base. Due to the limited level of technological development, it is temporarily unable to control the discharged waste more effectively. From the comprehensive utilization rate of industrial solid waste, it can be seen that the utilization rate of solid waste in the northwest region is relatively low, which further verifies the reality that the eco-efficiency of industrial enterprises in this region is relatively low.

### Factors Affecting the Eco-Efficiency of Industrial Enterprises

Moran's I, which reflects the global spatial autocorrelation, indicates that there is a certain spatial correlation in the eco-efficiency of industrial enterprises. And the influence of spatial weight must be taken into account when measuring the influencing factors of eco-efficiency. Therefore, this paper constructed the spatial error model and the spatial lag model to measure the influence factors of industrial enterprise's ecological efficiency by the software R-Studio Version 1.1.453.

In the model, eco-efficiency is taken as a dependent variable and the influencing factors as independent variables to calculate the spatial econometric model. The results are shown in Table 2.

Table 2 showed that except for stochastic effect and fixed effect estimations, the influencing factors have a significant effect on the eco-efficiency of industrial enterprises as a whole. And the decision coefficient  $R^2$  of each model indicates that the analysis effect of the model is good. Per-capita GDP ( $Z_2$ ) has a significant positive impact on industrial eco-efficiency in space, and the influence coefficient is small. The regional economic situation is enough to become an important symbol to distinguish the level of eco-efficiency. The regional economic development urges industrial enterprises to pay more attention to sustainable development and ecological development of new ideas. However, the positive effect of Fujian's regional economic development on the ecological efficiency of industrial enterprises has not yet been fully realized. It is necessary to continue to strengthen the concept of "green" GDP and new ideas of "lucid waters and lush mountains" being invaluable assets. And to avoid using traditional economic development indicators as the only index to measure regional development.

Population density ( $Z_1$ ) and the proportion of industrial output value ( $Z_3$ ) have significant positive effects on eco-efficiency. Among them, population density has a significant positive impact on eco-efficiency at the level of 1%, which verifies the research conclusions of Wang et al. (2017). The higher

Table 2. Spatial econometric analysis of the eco-efficiency of industrial enterprises.

Variable	Stochastic effect estimation	Fixed effect estimation	Spatial error model	Space lag model
$Z_1$	0.002**	0.007	0.002**	0.001**
$Z_2$	0.000*	0.000	0.000*	0.000*
$Z_3$	0.004	0.003	0.005*	0.057*
$Z_4$	-0.020**	-0.018	-0.020**	-0.004**
$Z_5$	-0.451**	-0.135	-0.462**	-1.450**
$Z_6$	0.001	0.001	0.001*	0.016*
$R^2$	0.662	0.515	0.661	0.661

Note: \*\*, \* indicate significance at levels of 1% and 5%, respectively

the population density, the stronger the local ability to attract talents, and the more powerful protection of talents for regional economic development. The introduction of high-caliber talents is conducive to accelerating technological progress and promoting economic development, which provides technical support for the protection and control of the industrial ecological environment. In addition, the proportion of industrial output value also has a significant positive impact on eco-efficiency. The increase of the proportion of industrial output value can improve the status of industry in the industrial system, and can also promote the formation of industrial clusters and the optimal allocation of resources. It can expand the marginal benefits of industrial industry in the process of development, and can also control and manage the waste discharged by industrial enterprises in a unified way.

Table 2 also showed that the ratio of value of imports and exports goods to GDP ( $Z_4$ ) and the ratio of expenditure on R&D to general public expenditures ( $Z_5$ ) have a negative effect on the eco-efficiency of industrial enterprises, which is significant at the 1% level. This indicates that Fujian should further optimize the structure and proportion of imports and exports. It is necessary to formulate the corresponding management system and take the corresponding measures to effectively regulate "foreign garbage," including clothing, plastics, electronic digital products, etc. In addition, the variable  $Z_5$  reduces the eco-efficiency of industrial enterprises, which indicates that Fujian should strengthen the management of expenditure on science and technology. It should be ensured that funds are actually spent on basic research, applied research and experimental development conducive to increasing eco-efficiency.

The comprehensive utilization rate of industrial solid wastes ( $Z_6$ ) has a significant positive spatial impact on the eco-efficiency of industrial enterprises, which is not only in line with the statistical results of the data, but also with the actual situation. As far as the current situation is concerned, the comprehensive utilization rate of industrial solid waste in the districts and cities with high eco-efficiency of industrial enterprises is relatively

high, and it is basically kept at more than 90% except for a few years. However, the comprehensive utilization rate of industrial solid waste is even lower than 50% in the cities with low eco-efficiency, which shows that there are great differences in this index among different districts and cities. Judging from the development trend, the utilization rate for the vast majority of districts and cities maintained at a relatively stable level and improved year by year. This indicates that local governments and industrial enterprises have a new understanding of the management and utilization of industrial solid waste through the use of scientific and reasonable means to increase the utilization of industrial waste, which makes the protection of the ecological environment at the same time in order to promote enterprise development and economic growth.

## Conclusions

Based on the statistical data of Fujian Province from 2011 to 2016, this paper analyzed the eco-efficiency of industrial enterprises by using the super-efficiency DEA model and spatial metrology. The main conclusions are as follows.

(1) The eco-efficiency of industrial enterprises fluctuates in time distribution, and has certain geographical characteristics in spatial distribution. According to statistics, the eco-efficiency values of industrial enterprises in Fujian's cities and districts showed an overall upward trend. Only Zhangzhou, Longyan, Ningde and Putian showed a downward trend in some years, but they were all further improved afterward. On the whole, Fujian has strengthened its green development, combined with the concept of sustainable development, changed the mode of economic growth, and steadily pushed forward on the development path of "building a new Fujian on a new level." In addition, the eco-efficiency of industrial enterprises in different districts and cities of Fujian is quite different, and it is expanding with the passage of time. The efficiency value in the eastern part of Fujian is higher than that in the southwest, and the one

in the northwest is the lowest, which is related to the distribution of heavy industry in each region. It shows that the effective evaluation of waste discharge system and green development should be paid more attention by governments and enterprises. Moran's I also indicates that there is a certain spatial autocorrelation in the eco-efficiency of industrial enterprises.

(2) The parameter estimation of the spatial econometric model shows that most variables have significant positive or negative effects on efficiency. The results show that population density, per capita GDP, proportion of industrial output value and comprehensive utilization rate of industrial solid waste have a significant positive effect on the eco-efficiency of industrial enterprises in space, which is similar to many existing research conclusions, but the influence coefficient is smaller. These indicate that the significant effect of many factors has not been paid enough attention. For example, the talent agglomeration effect generated by the introduction of talent has not been fully reflected. In addition, the ratio of value of import and exports good to GDP and the ratio of expenditure on R&D to general public expenditures have significant negative effects on the eco-efficiency of industrial enterprises, which further illustrates that the structure of imports and exports and the expenditure on science and technology need to be further standardized. In particular, the positive impact of scientific and technological development on eco-efficiency needs to be further strengthened.

From the above conclusions, the eco-efficiency of industrial enterprises is affected by many factors, including economic development and population density, as well as expenditures on science and technology. Obviously, the construction of an ecological civilization and the building of a beautiful China will become one of the future directions of social and economic development. In order to improve eco-efficiency of industrial enterprises in Fujian Province, we have several policy recommendations:

1) Establish and improve the waste discharge system and ecological evaluation mechanism. Research has shown that the comprehensive utilization rate of industrial solid waste has a significant positive effect on eco-efficiency. In order to ensure that the ecological efficiency of industrial enterprises can be further improved, the government should establish a sound mechanism of rewards and punishments for ecological efficiency, and gradually promote the ecological concept and ecological consciousness of industrial enterprises. Also, it should strengthen the ecological protective action. Appropriate incentives should be given to industrial enterprises that make efforts to implement eco-protection mechanisms and improve eco-efficiency, and punishment should be given to industrial enterprises that fail to improve eco-efficiency. Enterprises should strengthen the cultivation and enhancement of employees' ecological consciousness, which is not

only helpful for promoting the production efficiency of enterprises, but also conducive to enterprises to maintain long-term sustainable development. Technically, industrial enterprises can promote the technological reform of waste utilization and improve the comprehensive utilization of waste through the introduction of high-caliber talents. The government and enterprises should weaken the influence of the traditional economic development indicators on eco-efficiency, and strengthen the correlation between the input of science and technology, the level of development and eco-efficiency. The government needs to gather all kinds of forces to form a system of ecological development and environmental management of industrial enterprises. Among them, local governments at all levels are responsible for establishing and improving the corresponding evaluation mechanism. Industrial enterprises are responsible for pollution control, and the public is involved in the protection of the ecological environment, which is to be monitored from the source, the process, and the consequences. At the same time, a lifelong accountability system for environmental pollution has been established to jointly enhance the ecological efficiency of industrial enterprises in Fujian.

2) Establish and improve the evaluation mechanism of green development. Traditional economic development focuses on short-term benefits, and pays insufficient attention to the possible negative environmental effects. In recent years, large-scale environmental pollution incidents have occurred all over the country, which has brought a certain blow to economic development. Blindly pursuing economic profits and ignoring the requirements of environmental protection can no longer provide long-term support for regional economic development. The new ideas of green development put forward by the Chinese government is the basic concept that should be followed in regional economic development and enterprise development. Per-capita GDP and the proportion of industrial output value have a significant effect in promoting eco-efficiency, which means that the increase of per-capita GDP strengthens the concept of green consumption, and the focus on green products and environmentally friendly products continues to rise. This further points the way to the production of industrial enterprises. In addition, "foreign garbage," including clothing, plastics and electronic digital products has become an obstacle to green development. Thus, the government should establish and sound the corresponding mechanism to examine the import and export commodity trade in order to effectively control the entry of this "garbage."

3) The government should increase expenditure on R&D, enhance the effectiveness of talent introduction, and further improve the training system of innovative talents. The improvement of



eco-efficiency of industrial enterprises depends on a large number of technological improvements and innovations. The level of expenditure on R&D reflects the government's emphasis on research and development work and also indicates the strength of regional technology R & D capabilities. A large amount of effective expenditures on R&D not only attracts high-caliber talents, but also promotes the aggregation of talents and high-tech industries, which is conducive to forming a strong agglomeration effect and providing a large number of scientific and technological support and talent support for the development of industrial enterprises. The agglomeration effect of talents has been confirmed in the research, which is due to the population density significantly promoting the improvement of eco-efficiency. On the one hand, the influx of talents brings new vitality to local economic development; on the other hand, it also produces a larger agglomeration effect. Many talents with innovative thinking and skills have brought potential and improvement to regional economic development and have also become an important support for the sustainable development of the regional economy. In addition, the training system for innovative talents needs to be further optimized and improved. The traditional mode of personnel training is no longer suitable for the needs of social and economic development at present, and the development of enterprises requires the participation of a large number of innovative talents. Therefore, the governments, universities and enterprises related to talent training should create as good a training environment as possible and optimize personnel training systems, so as to truly shape personnel training into new types of talent with strong innovative thinking and capabilities.

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### Conflict of Interest

The authors declare no conflict of interest.

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