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Research on the Characteristics and Equilibrium of Ecological Efficiency in Guangdong Province

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Abstract: DEA-Malmquist index model is used to measure the ecological efficiency of Guangdong province, and to investigate the spatial and temporal evolution characteristics and regional development imbalance of ecological efficiency in 21 cities. The global Moran index results show that the global correlation of ecological efficiency in all cities in Guangdong is high from 2003 to 2021. The results of Dagum-Gini coefficient show that there are obvious differences in ecological efficiency in "One Core, One Area and Three Regions". Further analysis shows that the unbalanced development of ecological efficiency in the province mainly comes from the development differences between regions. Finally, the reasons and policy factors of the unbalanced development of ecological efficiency are analyzed.

Keywords: Dagum-Gini Coefficient; Ecological Efficiency; DEA Model

1. Literature Review

A large number of domestic and foreign documents evaluate ecological efficiency from different perspectives, mainly focusing on national, provincial or industrial research, while there are few studies on ecological efficiency from prefecture-level evaluation. As an entity unit of a countrys economic operation and social management, cities play an important basic role in protecting the ecological environment. In essence, the ecological environment governance work of a country, a region and a province is implemented at the prefecture-level administrative level. Therefore, it is very necessary to investigate the achievements of environmental protection and ecological improvement in China from the perspective of municipal ecological environment improvement and governance. Because China has a large territory and abundant resources but a large gap in regional development level, it is one of the most unbalanced economic developments in the world, and the city is the main unit of the imbalance. As Chinas largest province of economy, the largest population and the forefront of reform and opening up, Guangdong also has the phenomenon of regional gap in uneven development. Therefore, this study is to investigate the dynamic evolution process of the ecological efficiency of each city from the municipal level of Guangdong Province, and to incorporate policy factors into the model, to investigate the effect of the highly representative low-carbon pilot city.

The discussion of ecological efficiency mainly focuses on the concept, evaluation, spatial difference analysis and causal logic relationship. Ecological efficiency has two meanings: first, to achieve economic growth under the condition of not increasing or even decreasing resource input. Second, under the condition that the economic output remains unchanged or even increasing, the waste discharged to the environment is greatly reduced. In 1998, the Organization for Economic Cooperation and Development (OECD) extended the concept of ecological efficiency to the whole economic field such as government and industrial enterprises, defined ecological efficiency as the efficiency of ecological resources to meet human needs, and pointed out that ecological efficiency is the use of natural resources to protect the environment under the premise of optimal technological and economic efficiency. In 2001, the World Business Council for Sustainable Development proposed three main objectives for implementing ecological efficiency, namely, to reduce the consumption of resources, reduce the impact on nature, and improve the value of products or services. the Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment of China defines ecological efficiency as the

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efficiency of ecological resources to meet human needs, which can be measured by the ratio of output and input. Overall, the connotation of ecological efficiency in reducing consumption and increasing desired output is consistent.

The evaluation methods of ecological efficiency mainly include single ratio method, index system method and non-parametric model method. the single ratio method can only give a simple ratio, and cannot distinguish between different environmental influences. the index system method can comprehensively reflect the development level and coordination degree of social, economic and natural subsystems, but the method is susceptible to the deviation caused by human subjective factors in the weighting process. Model method can make up for the shortcomings of these aspects, in recent years, data envelope method (DEA) is widely used in the study of ecological efficiency, DEA method by Charnes is equal to 1978[1], is based on the input-output data research to evaluate unit relative efficiency of nonparametric method, gradually become the main measure of agriculture, industry, regional ecological efficiency. Zhang& Liu measured the three-stage data of 30 provinces in China. Zhang Renjie et al [2]. Zhang measured the industrial ecological efficiency of 31 provinces in China based on the unexpectation SBM model [3]. Chen Minghua et al. used the MinDS model to calculate the ecological efficiency level of the Yellow River basin [4]. It can be seen that the measure of ecological efficiency usually relies on the provincial region and industry data. This paper intends to reduce the scope of ecological efficiency measurement to city level, and expand industry oriented to city oriented.

The literature studies spatial differences in ecological efficiency using quantile regression, traditional Gini coefficient or Thiel index. For example, Jiang Shuoliang et al. used the quantile regression method to analyze the internal spatial differences of industrial ecological efficiency in the urban agglomerations along the Yangtze River Economic Belt [5]. Wang Yantao et al. explored the situation of ecological efficiency differences in different regions by using the Gini coefficient and the Tyr index respectively [6]. Zhang Zhen used the Tyre index to measure the regional differences of Chinas industrial ecological efficiency in the new period [7]. What is insufficient is that most of the above methods are difficult to reveal the specific sources of spatial differences and often ignore the specific distribution of subsamples. the Dagum Gini coefficient can avoid the above problems. For example, Yu Wei et al. used the Dagum Gini coefficient and its decomposition method to explore the ecological efficiency differences and their sources of the eight urban agglomerations in China [8]. the dynamic change of ecological efficiency over time is mainly measured by Malmquist index method. Malmquist index is a method used to measure the change of total factor productivity. For example, Li Jinkai et al. analyzed the dynamic change of energy carbon emission efficiency in the eight comprehensive economic zones of China based on the three-stage DEA-Malmquist index model [9].

In general, scholars have relatively perfect research on ecological efficiency, but there are still the following problems: the applied research focuses on the micro enterprise level and industrial level. In fact, the government can also apply the concept of ecological efficiency to examine the sustainable advantages in the long-term development of the country or region. However, at the regional level, the current research mainly focuses on national and provincial levels, and research on medium social units are scarce. Therefore, this study focuses on the ecological efficiency of 21 cities in Guangdong Province, and probes the spatiotemporal and heterogeneous spatial characteristics. the rest of this article is arranged as follows: First, DEA-Malmquist index is used to measure the ecological efficiency level of panel data in 21 cities in Guangdong, and then Dagum Gini coefficient, Moran index and geographic weighted regression model are used to conduct spatial correlation and heterogeneity analysis, and finally put forward policy suggestions.

2. Evaluation Of the Ecological Efficiency

The classic concept of ecological efficiency is defined from the perspective of input and output, in recent years the mainstream evaluation method is to use the data envelope model (Data Envelopment Analysis), the method is the Charnes, Cooper and Rhodes three scholars in 1978 first proposed a non-parametric technical efficiency analysis method, by comparing the input and output is the best efficiency performance.

2.1 Indicators

The input indicators of measuring ecological efficiency are: capital, labor, science and technology and energy. the output indicators are: economic value, environmental output and pollutant quantity, in which economic value and environmental output are expected output, and the quantity of pollutants is undesired output. Specifically, the annual capital investment of fixed assets investment (1 billion yuan), the labor investment with the annual number of employees (10 thousand people), science and technology investment with science and technology expenditure (10 thousand yuan), energy investment with annual electricity consumption (10 thousand kilowatt-hours). Economic value is expressed by GDP (1billion yuan), environmental output is expressed by garden green area (100 hectares), and the number of pollutants is expressed by PM2.5 index. the actual price of regional GDP is based on the year 2000 period.

The data used in this study were all from the statistical yearof 21 cities in Guangdong Province, and supplemented with CEIC database. the descriptive statistical characteristics of each indicator are shown in Table1. This sample covers 21 cities and cities in Guangdong Province, with a data range of 21 years from 2001 to 2021. the total sample size is 441. the missing values are supplemented by linear interpolation method.

Table 1. Descriptive Statistical Characteristics of Each Indicator

Indicator category	Name	Sample size	Minimum	Maximum	Mean	Standard deviation	Median
Input factors	Investment in fixed assets (billions)	441	2.088	850.275	96.702	126.511	58.52
	Number of employees	441	883	12913.1	2836.874	2259.188	2118.541
	Electricity consumption	441	0.247	111.973	19.86	23.021	11.105
	Science&Technology Expenditure	441	2.09	55498.18	1671.224	5749.274	199.84
Desired output	GDP (billion)	441	9.728	3082.01	278.49	465.38	114.224
	Landscaped area (hundred hectares)	441	2.22	1485.4	158.322	331.797	37.86
Non-desired output	Pollutant (PM2.5)	441	19.064	52.474	34.394	6.829	34.756

2.2 Analysis results

The traditional DEA model is based on the cross-section data of a specific period, analysis is the technical efficiency of each decision unit DMU in a specific period, is for a specific period, for this study contains multiple time observation panel data, need to analyze the production efficiency changes over time, so need to use Malmquist total factor productivity (TFP) index analysis [10]. When the data of DMU is the panel data containing the observed values of multiple time points, it can analyze the change of productivity and the role of technical efficiency and technological progress in the change of productivity, which is the commonly used Malmquist total factor productivity (total factor productivity, TFP) index analysis. Since the output of ecological efficiency needs to consider pollutant discharge, and each input and output elements are not proportional changes, and the sample data covers multiple periods, the mixed distance ultra-efficiency Malmquist model with input-oriented unexpected output and variable return of scale is used to calculate the ecological efficiency index. $\mathrm{Score\_f}(x_t, y_t)$ represents the DEA efficiency value from the reference fixed front (xt, yt), and represents the DEA efficiency value from the reference fixed front (xt-1, yt-1). In this paper, the TFP calculated in 2001 as a fixed reference frontier is used as the ecological efficiency index. Therefore, although the data span of this study is 2001-2021, the calculated ecological efficiency value starts from 2003.

$$\mathrm{MI}(t-1,\ t)=\frac{Score\_f(x_t, y_t)}{Score\_f(x_{t-1}, y_{t-1})} \quad (1)$$

Figure 1 shows the average ecological efficiency in 2003-2021. the highest average is Shenzhen 1.24, followed by Guangzhou 1.19, Maoming 1.10, Foshan 1.09, Dongguan 1.07 and Jieyang 1.06. the ecological efficiency values of other cities are all below 1. the ecological efficiency value of Guangdong province is the lowest 0.35 and the highest 1.24, and the gap is still large. Therefore, there is an obvious unbalanced development of ecological efficiency in Guangdong province.

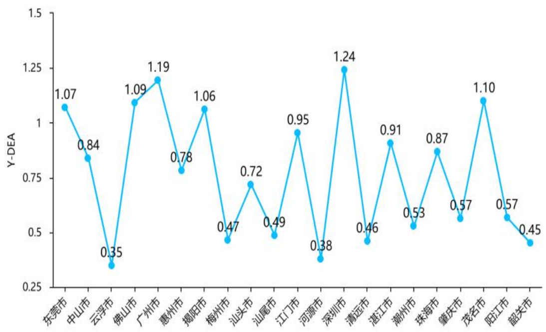

Figure 1. Average Value of Ecological Efficiency Across Local Cities (2003-2021)

3. The Spatial Correlation of Ecological Efficiency

Spatial autocorrelation is spatial dependence. If there is obvious spatial correlation, the spatial effect is needed to be included in the analysis framework of the regression model, and the appropriate spatial econometric model is used for regression estimation. If there is no spatial effect, the general estimation method (such as OLS) can be directly used to estimate the model parameters. Here, we will not discuss the regression model, but only examine whether there is spatial correlation between ecological efficiency and cities. the global Moran index can measure the degree of global spatial correlation, mainly describing the average correlation of all spatial units in the whole region. the global Moran exponent is calculated with the formula (2).

$$I = \frac{n}{S_0} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} \omega_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{2}$$

Where, $S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}$, n is the total number of spatial cells, and represent the attribute values of the i-th and j-th spatial cells, respectively, are the mean of the attribute values of all spatial cells and the spatial weight value. the spatial unit weight values are represented using the spatial weight matrix, a matrix used to quantify the mutual influence between the spatial cells. Each element in the matrix represents the strength of the spatial connections between the two spatial cells. Each position of the matrix represents the spatial relationship of the rows and column cells. Here, the spatial unit is all 21 cities in Guangdong Province, and the attribute value is ecological efficiency. the spatial weight value is set by whether the cities belong to the same partition. If it belongs to the same partition, ω_{ij} =1, if it does not belong to the same partition, ω_{ij}=0.

The value of the global Moran index I ranges from [-1, 1]. I> 0 indicates that the attribute value of all cities has a positive correlation in space, that is, the larger the attribute value (the smaller), the easier it is to gather together. I=0 indicates the random distribution of regions, no spatial correlation, I <0 indicates that the attribute values of all cities have a negative correlation in space, that is, the larger the attribute value (the smaller), the easier it is to gather together. However, after calculating the Moran index I, its spatial correlation cannot be judged immediately based on its positive and negative results. Also test the hypothesis to see if it can pass the test. the original hypothesis is that "all research units are randomly distributed in space" (i. e. I=0).

The p-value of the global Moran index, based on the results was less than 0.05 in any year, and the global Moran index I in 2003-2021 were positive, ranging from 0.133 to 0.554, which indicates a significant positive spatial correlation of ecological efficiency in cities across Guangdong Province. In 2020, the global Moran index was the lowest 0.133, and the global Moran index in 2018 was the highest 0.554.

4. Spatial Heterogeneity

The Dagum Gini coefficient is a measure of the imbalance. the Dagum Gini coefficient can not only effectively solve the source of regional gap, but also describe the distribution of subsamples, and solve the problems of small sample, heteroscedastic and asymmetric distribution of the Taylor index [11, 12, 13, 14]. This method decomposes the overall Gini coefficient G into three parts: regional Gini G_w, interregional Gini G_{nb} and hypervariable density coefficient G_t, i. e., $G = G_w+G_{nb}+G_t$.

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_k}|y_{ji}-y_{hr}|}{2n^2\mu} \quad n=21,\ k=3 \tag{3}$$

$$G_{jj} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji}-y_{hr}|}{2\mu_j n_j^2} \tag{4}$$

$$G_w = \sum_{j=1}^{k} G_{jj}\, p_j s_j \tag{5}$$

among,

$$p_j = \frac{n_j}{n} \tag{6}$$

$$s_j = \frac{n_j \mu_j}{n\mu} \tag{7}$$

$$G_{jh}=\frac{1}{n_j n_k(\mu_j+\mu_h)}\sum_{i=1}^{n_j}\sum_{r=1}^{n_k}\left|y_{ji}-y_{hr}\right| \quad (8)$$

$$G_{nb}=\sum_{j=2}^{k}\sum_{k=1}^{j-1}G_{jh}(p_j s_h+p_h s_j)D_{jh} \quad (9)$$

$$G_t=\sum_{j=2}^{k}\sum_{h=1}^{j-1}G_{jh}(p_j s_h+p_h s_j)(1-D_{jh}) \quad (10)$$

$$D_{jh}=\frac{d_{jh}-p_{jh}}{d_{jh}+p_{jh}} \quad (11)$$

$$d_{jh}=\int_0^{\infty}dF_j(y)\int_0^{y}(y-x)dF_h(\mathrm{x}) \quad (12)$$

$$p_{jh}=\int_0^{\infty}dF_h(y)\int_0^{y}(y-x)dF_j(\mathrm{y}) \quad (13)$$

The calculation formulas of G, G_w, G_{nb} and G_t are equations (3), (5), (9) and (10), respectively, which depict the size and source of the relative difference of ecological efficiency in the three regions of Guangdong Province. Formula (4) is the Gini coefficient G_{jj} in the j-th partition, Formula (8) is the Gini coefficient G_{jh}, Ecological efficiency distribution of $y_{ji}(y_{hr})$ in area j (h), μ Is the ecological efficiency distribution of n cities, the k is the three major divisions of Guangdong Province, N_j ($_{nh}$) is the number of cities in the first j (h) division; D_{jh} of formula (11) is the relative influence between the ecological efficiency of areas j and h; the d_{jh} of formula (12) is the difference of ecological efficiency between regions (the j-th region and the h-th region), the mathematical expectation $F_h(x)$ of all sample values of $y_{ji}> y_{hr}$ in the j, h region is the cumulative distribution function of the j-th partition; P_{jh} is the mathematical expectation of sample values of $y_{hr}> y_{j,}$ $F_j(y)$ is the cumulative distribution function of the h-th partition.

This paper divides the ecological efficiency of Guangdong province into three divisions according to the policy of "One core, One belt, One zone". One core, that is, the 9 cities in the core area of the Pearl River Delta, one belt refers to 7 cities in the coastal economic belt, and one zone refers to 5 cities in the northern ecological development zone. the division of Guangdong Province into three divisions was designed to analyze within-group and between-group differences of ecological efficiency in the three regions using the Dagum Gini coefficient.

Table 2. One core, One belt, One zone of Guangdong Province

Regional Division	Cities
One core	Guangzhou, Shenzhen, Foshan, Dongguan, Zhuhai, Zhongshan, Huizhou, Jiangmen, Zhaoqing
One belt	Shantou, Shanwei, Jieyang, Chaozhou, Zhanjiang, Maoming, Yangjiang
One zone	Shaoguan, Meizhou, Qingyuan, Heyuan, Yunfu

Table 3. Dagum Gini Coefficient and Their Composition

	Gini coefficient				Contribution (%)		
Year	Overall	Within-group Gini coefficient Gw	Between-group Gini coefficient Gb	Hypervariable density Gini coefficient Gt	Within-group contribution Gw	Between-group contribution Gb	Hypervariable density contribution Gt
2003	0.313	0.089	0.155	0.069	28.31%	49.54%	22.16%
2004	0.3	0.082	0.169	0.049	27.34%	56.25%	16.41%
2005	0.306	0.082	0.192	0.032	26.81%	62.75%	10.44%
2006	0.329	0.089	0.206	0.034	26.98%	62.59%	10.43%
2007	0.35	0.093	0.209	0.048	26.70%	59.67%	13.63%
2008	0.332	0.086	0.202	0.043	26.04%	60.96%	13.00%
2009	0.339	0.088	0.211	0.041	25.88%	62.15%	11.98%
2010	0.315	0.077	0.198	0.04	24.41%	62.80%	12.79%
2011	0.29	0.063	0.201	0.026	21.83%	69.35%	8.82%
2012	0.271	0.055	0.198	0.018	20.22%	73.07%	6.71%
2013	0.259	0.055	0.184	0.02	21.30%	70.95%	7.75%
2014	0.256	0.053	0.182	0.021	20.60%	71.37%	8.03%
2015	0.238	0.048	0.171	0.02	20.04%	71.70%	8.27%
2016	0.204	0.043	0.137	0.024	21.19%	67.03%	11.78%
2017	0.196	0.041	0.132	0.023	21.04%	67.19%	11.78%
2018	0.155	0.029	0.106	0.02	18.61%	68.69%	12.70%
2019	0.111	0.023	0.07	0.018	20.78%	63.22%	16.00%
2020	0.05	0.015	0.021	0.014	30.03%	41.19%	28.78%
2021	0.057	0.016	0.03	0.01	28.01%	53.53%	18.46%

Table 3 shows the group In Gini coefficient G_w, component G_{nb} and G_t of the hypervariable density Gini coefficient. These three factors together contribute to the overall Gini coefficient G. the overall Gini coefficient is reduced year by year, indicating that the phenomenon of unbalanced development of ecological efficiency in various regions is

constantly weakening. It can be said that the ecological efficiency of the whole province is stepping into the path of balanced development. At the same time, it was also observed that after the decomposition of the overall Gini coefficient, the value of the Gini coefficient was between 0.015 and 0.093, indicating that the difference within the group was small, and with the delay of time, the value of the Gini coefficient in the group gradually decreased, especially after 2010, the gap within the group narrowed year by year. the value of Gini coefficient G_{nb} between groups ranged between 0.021 and 0.211. Numerically, the difference between groups was greater than the difference between groups, and the difference between groups experienced the change of first expanding and then narrowing. From 2003 to 2009, the ecological efficiency gap gradually widened, and the ecological efficiency gap gradually narrowed from 2011.

Figure 2 shows the disassembly of the Dagum Gini coefficient, which can directly compare the proportion of each gini coefficient. As can be seen from the figure, the ecological efficiency difference of the three divisions of one core, one area and one area in Guangdong Province mainly comes from the gap between groups, so the location characteristics of ecological efficiency of cities in Guangdong Province are very obvious, and the influence of cities on urban ecological efficiency is significant.

(1)Contribution (%) (2)Within-group Gini coefficient decomposition

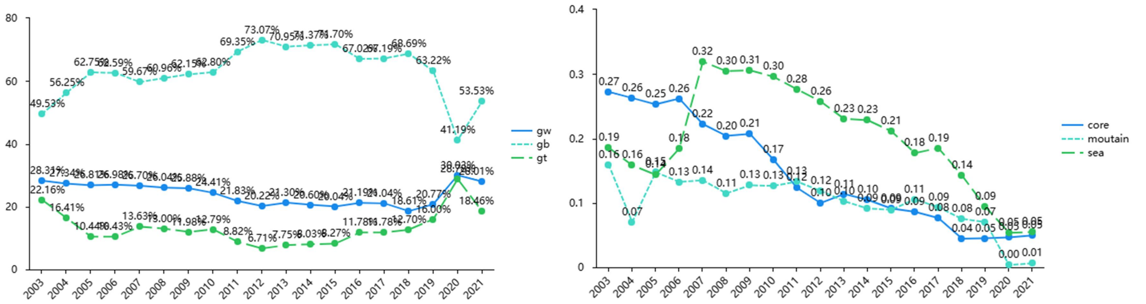

Figure 2. Contribution Rate of G_w, G_{nb}, G_t and Within-Group Gini Coefficient Decomposition

Figure 2 also shows the decomposition results of the Gini coefficient within the group, showing the internal Gini coefficient data of each partition, which can analyze the trend of the Gini coefficient within each group. As a whole, it can be seen from the figure that the internal differences of the cities in the eastern coastal area after 2007 are large, while the internal differences between the core development area of the Pearl River Delta and the northern ecological development area are relatively small. the three zones showed a consistent trend in the ecological efficiency gap between cities in the shrinking group. Even after 2020, the ecological efficiency gap between cities in the northern ecological development area has been close to 0.

5. Conclusion

According to the analysis results of the fourth part, it is obvious that the ecological efficiency value of 21 cities in Guangdong Province is obviously different. Especially, before 2017, the ecological efficiency of all cities in Guangdong Province was obviously unbalanced, but it gradually tended to equilibrium from 2018. Factors affecting ecological efficiency can explain the imbalance of ecological efficiency before 2017. the main reasons for the unbalanced development of ecological efficiency before 2017 come from policy and regulatory factors. Technological progress, the degree of opening to the outside world, urbanization level, energy price, industrial structure, financial agglomeration, and high-speed rail network will also affect the ecological efficiency. the studies of many scholars have affirmed the significant impact of policy factors on ecological efficiency, and they are promoting or positive effects [15, 16, 17]. Since the cities in the Pearl River Delta region are roughly distributed around provincial capitals and are economically strong, they attach more importance to environmental regulation policies. With the industrial transfer in recent years, heavy industry has been transferred to neighboring cities, which also explains that the ecological efficiency of the economic core area is higher than that of other regions. the empirical results of Cheng Jinhua research on the energy ecological efficiency of the Yangtze River Economic Belt show that: technological progress, environmental regulation, the degree of opening to the outside world, and cities and towns, Chemical level and energy price have a positive impact on energy ecological efficiency in the Yangtze River Economic Belt, which is conducive to improving energy ecological efficiency, while the industrial structure, energy consumption structure, ownership structure and energy endowment have a negative impact on energy ecological efficiency, which is not conducive to the improvement of energy ecological efficiency [18].

Therefore, it can be inferred that the implementation of environmental regulation policies, improving technological progress, boosting the upgrading of industrial structure, accelerating the development of urbanization, strengthening financial agglomeration, improving the level of opening up, optimizing the degree of the center of the high-speed rail network and other factors can improve the urban ecological efficiency.

Due to the different geographical locations, resource endowments and functional positioning of various cities in Guangdong Province, the unbalanced development of ecological efficiency seems inevitable. Among the many influencing factors, there are natural endowment factors that are difficult to change objectively, and there are also human factors that can exert influence subjectively. For non-core cities, it is difficult to achieve in the short term by improving the level of financial agglomeration, opening up to the outside world and optimizing the degree of high-speed railway network due to geographical conditions. Therefore, if we want to further change the unbalanced phenomenon, we can start with such factors as increasing environmental regulation policies, improving the speed of technological progress of enterprises, accelerating industrial upgrading, and accelerating the development of urbanization.

In terms of promoting industrial transfer, Guangdong Province has issued a number of policies in the past more than 20 years, which has made remarkable achievements in improving ecological efficiency, but also accelerated the unbalanced development. In 2008 The Guangdong industrial transfer area layout guidance " has been clear about the encourage the pearl river delta to the wings and north Guangdong mountains transfer industry has traditional labor-intensive industries, resource-based industries, capital intensive industries in the processing and manufacturing link, to turn to other industries driving function is weak or drive the power of industry, in a mature industrial cluster or production base of industry. In fact, this policy directly improves the ecological efficiency of the core area of the Pearl River Delta, and aggravates the ecological efficiency in the eastern and northern regions, which increases the imbalance. As can be seen from Figure 2 that the imbalance between groups tends to rise in 2008-2018.

Thus, environmental regulation, industrial structure adjustment, technological innovation, accelerate the development of urbanization actually need policy guarantee as a gripper, policy makers if you want to achieve the goal of improving ecological efficiency, can ensure the smooth and orderly economic development, and can realize ecological protection of low carbon development, then targeted policies to improve the possibility of policy landing and the implementation effect.

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