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Catch Up or Fall Behind on Eco-Efficiency: Insight from Convergence Analysis

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Eco-efficiency plays a crucial role in evaluating the green development of economics. Using the super slack-based measure approach, which considers carbon emissions and three kinds of industrial waste as undesirable outputs, this study examines the eco-efficiency of 48 cities in the Bohai Rim from year 2005 to 2015. Eco-efficiency exhibites a pattern of polarized disparity, with observable increase regional difference. Nonlinear time-varying factor and dynamic panel models are used to analyze the evolution and convergence of eco-efficiency. Analysis of club convergence revealed that the Bohai Rim area is divided into five groups by values and yearly changes of eco-efficiency. The analysis revealed that two groups show strong eco-efficiency and obvious growth paths, while the eco-efficiencies for the other three groups are weak, with stagnant growth paths. The results confirm the existence of relative β convergence through ordinary least squares and generalized methods of moments, and suggest that economic growth, foreign direct investment and fiscal decentralization have positive influences on eco-efficiency, while the development of secondary industry has negative effects on eco-efficiency.

1. Introduction

German scholars Schaltegger and Sturm (1990) proposed the concept of eco-efficiency which measures the ability to produce the most economic output with the least natural resources and environmental pollutions. Eco-efficiency assesses the regional input-output economic efficiency under the constraints of resources and environmental conditions to reflect the degree of green development. As an instrument for the analysis of sustainability, eco-efficiency stands for an empirical relationship between environment and cost of resources and economic obtainment (Chinnawornrungsee et al., 2013). As regional economic development becomes imbalanced, there must exist regional disparity in eco-efficiency. Many papers have studied industry structure (Zhou et al., 2019), urbanization (Zhou et al., 2020), ownership structure and environmental regulations (Wang et al., 2011), innovation (Cheng et al., 2019), urban clusters (Bai et al., 2018) as determinants of eco-efficiency. However, few papers have studied the size of these kinds of gaps at city level scale, and the evolution of this spatial difference at the time scale. Whether there is a catch-up effect, that is, convergence, for ecologically backward areas to keep up with more ecologically efficient areas, is worth discussing. This study answers a few of the questions listed above. It employed super Slacks Based Measure (SBM) with undesirable outputs to measure the eco-efficiency of 48 cities in Bohai Rim, from 2005 to 2015. ordinary least squares (OLS) and generalized methods of moments (GMM) are used to test the β convergence. The limitations of pre-classification and linear hypothesis were overcome by using the nonlinear time-varying factor model to test the club convergence of regional eco-efficiency and to examine the catch up effect.

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2. Methodology

2.1 Super slack-based measure with undesirable outputs

Data envelopment analysis (DEA) explores tools such as convex analysis and linear programming to measure the relative efficiency of multi-input and multi-output problems. A non-radial Slacks Based Measure (SBM) method is used to evaluate the efficiency of decision making units (DMU). Compared to the original radial DEA, the SBM model includes a slack variable in the measurement. Tone (2004) extended the scheme of the SBM model to consider undesired output. EE is the value of measured eco-efficincy using the super SBM approach, and its value can be more than 1.

2.2 Convergence analysis

σ convergence reflects the dynamic evolutionary trend of a region's deviation from the overall average development level. A coefficient of variation that shows a downward trend with time, indicates the existence of σ convergence. The following formula was applied to calculate the coefficient of variation.

$$CV = \frac{\text{Standard Deviation (EE)}}{\text{Average(EE)}} \tag{1}$$

β convergence describes the phenomenon of greater economic growth rate of countries with an initially low economic level than that of developed countries. After a period of time, the regions with initially lower economic level would catch up to the developed regions and eventually both regions would exhibit the same convergence state. β convergence includes absolute β convergence and conditional β convergence. Absolute β convergence assumes similar eco-economic fundamental conditions of different cities, so that the eco-efficiency of all cities can reach consistent steady-state growth rate and growth level with time. Conditional β convergence assumes diversified economic bases and varying characteristics of different cities. The eco-efficiency of each city will obtain their own respective steady-state levels. Hence eco-efficient gaps between regions may persist. The following equation was used in this study to test the absolute β convergence and the conditional β convergence.

$$\frac{1}{T}\ln\left(\frac{EE_{i,t}}{EE_{i,t-T}}\right) = \alpha + \beta \ln EE_{i,t-T} + \varepsilon \tag{2}$$

If β < 0, then there exists absolute β convergence. This study defines T=1, so the formula can be rewritten as:

$$\ln EE_{i,t} - \ln EE_{i,t-1} = \alpha + \beta \ln EE_{i,t-1} + \varepsilon \quad \ln EE_{i,t} = \alpha + (1+\beta) \ln EE_{i,t-1} + \varepsilon \tag{3}$$

Define r = 1 + β, and if r < 1, there is absolute β convergence. The same test equation for conditional β-convergence is

$$\ln EE_{i,t} = \alpha + (1+\beta_1) \ln EE_{i,t-1} + \beta_2 \ \ln p + \beta_2 \ \ln is + \beta_3 \ \ln pgdp + \beta_4 \ \ln p + \beta_5 \ \ln fd + \beta_6 \ \ln fdi + \varepsilon \tag{4}$$

Club convergence (Galor, 1996) describes the situation in which different economic groups converge to sub groups whose initial economic level is similar in institutions, locations, or natural conditions. There may be a convergence trend within sub groups, but there is no convergence between sub groups. Log t –test is always used to pre-test the club convergence and this test was used in this study.

2.3 Data sources

Due to the accessibility of data, this study utilized the annual data of 48 cities in Bohai Rim from years 2005 to 2015. The data was mainly from EPS database (EPS). Table 1 shows the indicator system used in super-SBM models to measure eco-efficiency.

2.4 Dependent variables

Table 2 describes several control variables for empirical conditional convergence analysis. Using the three-sector model of economic activity, secondary industry involves the transformation of raw or intermediate materials into goods, where extensive development is likely to cause serious damage to the ecological environment. Whether FDI or FD is favourable environmental qualify exists controversy. This study lets PGDP, FDI, FD, IS be the dependent variables of the models. Table 3 presents the descriptive statistics for these variables. Table 4 shows all variables in the models have passed the unit root tests.

3. Empirical results

3.1 Test of σ convergence

As shown in Figure 1, the coefficient of variation displays an overall downward trend with slight fluctuations, indicating there is σ convergence. It indicates with time going by, the gaps in eco-eco-efficiency are narrowed and there will be convergence in eco-efficiency among the cities in Bohai Rim. First, there is an uneven overall distribution of eco-efficiency in Bohai Rim with increasing polarized regional disparity.

Table1: Indicator system for slack based measure approach

Dimension layer	Criteria layer	Quantitative indicators
Input	Labor input	Employment population (10 k people)
	Resources input	Water consumptions (100 Mm^3)
		Electricity consumptions (3.6 x 10^{10} J)
		Built-up areas (km^2)
	Capital investment	Capital stocks (1.5 x 10^7 $)
Output	Desired output	GDP (1.5 x 10^7 $)
	Undesired outputs	Industrial sulfur dioxides (t)
		Industrial wastewater (10^4 t)
		Industrial smoke dust (t)

Table 2: Variable descriptions for variables in convergence analysis

Symbol	Variable	Definition	Unit
EE	Eco-efficiency	Product value corresponding to unit environmental cost	ratio
PGDP	Gross domestic product	Per Capita GDP	1.5 x 10^3 $
FDI	Foreign direct investment	The amount of the FDI covering the province's GDP	%
FD	Fiscal decentralization	Local fiscal revenue accounts for local fiscal expenditure	ratio
IS	Industrial structure	The added value of the second industry coving GDP	%

Table 3: Descriptive statistics for variables in convergence analysis

Variable	Obs.	Mean	Std. Dev.	Min	Max
EE	528	0.448	0.013	0.086	1.122
PGDP	528	4.4568	14.637	0.552	25.689
FDI	528	2.242	2.369	0.009	13.164
FD	528	56.340	19.124	12.276	97.002
IS	528	51.929	8.936	19.740	82.280

Table 4: Unit root test statistics for variables in convergence analysis

Variable	ADF	P	Conclusion
EE	250.196	0.000	stable
PGDP	170.288	0.000	stable
FDI	172.118	0.000	stable
FD	187.581	0.000	stable
IS	250.332	0.000	stable

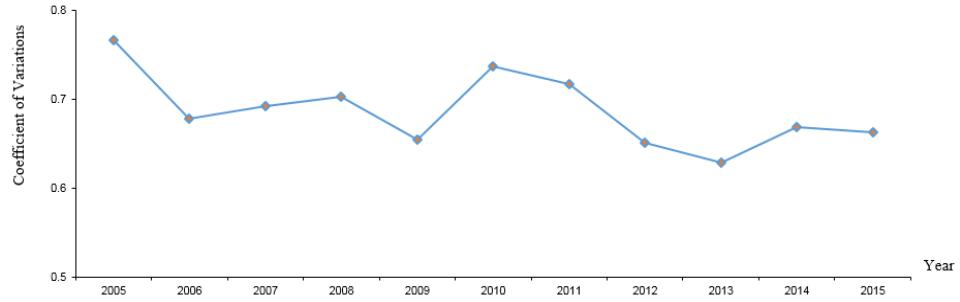

Figure 1:The evolution of σ convergence for eco-efficiency

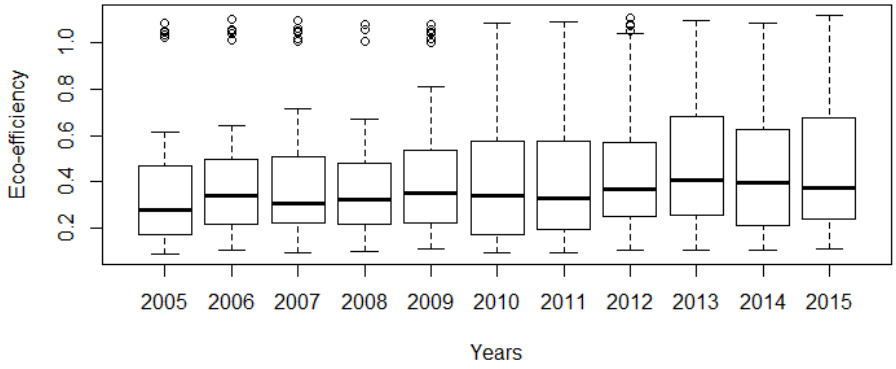

Figure 2: Box plot for eco-efficiency of cities in Bohai Rim

Based on Figure 2. The eco-efficiency of Beijing, Cang Zhou, Ordos, Qingdao, Yantai, and Weihai are all greater than 1 for the past ten years, but for more than half of the other cities, the eco-efficiencies are below 0.5. The average of eco-efficiencies for all cities is less than 0.5, which is quite low. Second, cities such as Beijing, Tianjian, Chengde, Baotou, Jinan, and Dongying exhibit an obviously increasing trend in eco-efficiency but other cities show notably large fluctuations in eco-efficiencies. Third, the eco-efficiencies for Tianjin, Hengshui, Huhehaote, Baotou, Liaocheng, Dezhou, and Dongying have surpassed or are equal to 1 in recent years. However, for Huhehaote, Liaocheng and Dezhou, eco-efficiencies have declined instantly after reaching these high eco-efficiency values.

Table 5: New clusters

	Provinces	b-coefficient	t-statistics
Group 1	Beijing, Tianjin, Cangzhou, Ordos, Baotou, Qingdao, Yantai, Dongying, Weihai, Hengshui, Hohhot	-0.5528	-0.3272
Group 2	Jinan, Weifang, Dalian, Liaocheng	-0.9447	-0.8333
Group 3	Shijiazhuang,Tangshan, Handan, Baoding Langfang, Ulanchabu, Bayannaoer Shenyang, Panjin, Zibo, Zaozhuang Dezhou, Puyang	-0.6119	-0.5095
Group 4	Xingtai, Chengde, Yangquan, Tongliao Dandong, Zhaoyang, Huludao, Binzhou, Qinhuangdao, Taiyuan, Jincheng, Chifeng, Rizhao, Anyang Zhangjiakou, Changzhi, Yingkou	-0.3391	-1.1464
Group 5	Datong, Xinzhou, Fuxin	0.8020	0.8096

3.2 Test of club convergence

According to the club convergence of eco-efficiency, Bohai Rim can be divided into five groups displayed in Table 5. Group 1 includes Beijing, Tianjin, Erdos, Dongying, and other cities with good economic foundations. The per capita GDP of Ordos and Dongying City ranked first and second, in China in 2017. A good economic level can attract advanced cleaner production technology, with talented people who possess a good background knowledge and management ability, which can indirectly reduce the generation and discharge of pollutants. Qingdao, Yantai, and other coastal areas have better tourism resources. High-quality tourism services in the urban economy also force the city to develop green industries and improve eco-efficiency. Group 2 represents the second highest ecological benefit zone, and consists of four cities, all in Shandong Province except Dalian, which is a coastal city. The cities of Group 1 and Group 2, as members of strong eco-efficiency clubs, share characteristics of solid economic foundations, well-developed tourism industry, cultural and creative exhibition industries, and sports industries. Group 3 and Group 4 include most cities in Hebei Province and Liaoning Province. With the rapid development of the economic level of Beijing and Tianjin and a coordinated development strategy between Beijing, Tianjin, and Hebei, high energy consumption and high pollution industries in Beijing and Tianjin have gradually shifted to surrounding areas. At the same time, relatively undeveloped areas are competing to accept the transferred enterprises to stimulate urban GDP and improve employment, which naturally results in poor eco-efficiency. Datong, Zhangzhou, and Fuxin are in Club 5 and are all mining cities, mostly with coal resources. Their economic development is relatively backwards, with a single industrial type. To more precisely compare the gaps among these clubs, the relative transfer path for the cities in Group 1 and Group 2 are greater than 1, while these values are less than 1 for Groups 3, 4, and 5.

3.3 Discussions

Club convergence has shown Bohai Rim can be divided into 5 subgroups. Given that the original ecological condition of each area is not the same, whether these subgroups converge to the same steady state was next examined using the existence of β convergence. The results in Table 6 show that the eco-efficiency of the Bohai Rim area exhibits conditional β convergence. These results suggest several economic factors influence eco-efficiency. Economic development promotes eco-efficiency. Per capita GDP is statistically significantly positive in models using GMM. In areas with high levels of economic development, the government may pay more attention to environmental protection by strengthening ecological civilization and increasing investment into pollution control measures. Clean production technology promotion will vigorously enhance eco-efficiency by reducing undesired output. Higher GDP enables the government to pay more attention to science and technology education, which fundamentally improves the quality of the overall population education level, which subsequently benefits technology development. The advancement of science and technology can directly increase the output value and improve the ecological efficiency by increasing the expected output.

Table 6: GMM Results for β convergence

	GMM1	GMM2	GMM3	GMM4	GMM5	GMM6
L.EE	0.966***	0.912***	0.913***	0.884***	0.908***	0.945***
	(93.89)	(37.50)	(27.50)	(23.70)	(38.40)	(28.08)
PGDP		0.096***	0.095**	0.090**	0.046*	0.065***
		(3.34)	(2.53)	(2.37)	(1.80)	(3.37)
IS			0.017	-0.103	0.130	0.089
			(0.10)	(-0.53)	(1.07)	(0.98)
FDI				0.065**		0.017
				(2.09)		(1.18)
FD					0.112*	-0.050
					(1.69)	(-0.61)
Obs	432	432	432	431	432	431
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.043	0.053	0.053	0.064	0.051	0.056
Hansen	0.448	0.309	0.173	0.142	0.998	1.000

t statistics in parentheses.

* p < 0.1, ** p < 0.05, *** p < 0.01.

Industrial structure has negative effects on eco-efficiency. In the past ten years, the industrial structure of the Bohai Rim area has gradually transformed, and secondary industry is in a dominant position. Secondary industry mostly contains industries with higher energy consumption and higher pollution emissions than the more environmentally-friendly tertiary industry, restricting the sustainable economic development of the Bohai Rim

region (Zeng et al., 2019). Therefore, a top priority should be to reduce the proportion of secondary industry and increase the proportion of tertiary industry for ecologically stable development of the Bohai Sea region.
FDI benefits eco-efficiency. In GMM 4, the coefficient of FDI is 0.065 and is statistically significant, suggesting that FDI has a positive effect on eco-efficiency. According to the “pollution halo hypothesis,” developed countries usually have strict policies on environment protection. Foreign companies from developed countries are adapted to harsher environment regulations, so their pollution emissions are usually lower than local levels. Foreign direct investment not only brings abundant capital to economic development, but also provides advanced green technology. To maintain competitive relationships with foreign companies, local companies quickly imitate and update to eliminate equipment that is not environmentally friendly and have low productive value. FD also plays a positive role in eco-efficiency, as shown by GMM 5. Efficiency is promoted if the local government has greater tax authority and expenditure responsibility. The Chinese government has included environmental conditions as a significant factor in the performance evaluation for governors, local authorities have invested in environmental protection and enacted more regulations to reduce pollution.

4. Conclusions

Based on the above discussion, the main results are as follows:
(1) Only a few cities have high eco-efficiencies that are greater than 1, while a large majority of cities in Bohai Rim have unfavorable eco-efficiencies which are below 0.5.
(2) The Bohai Rim area is divided into five groups with two strong eco-efficiency groups and three weak eco-efficiency groups. Two groups have strong eco-efficiency and a smooth growth path, but the eco-efficiencies for the other three groups are weak with a stagnant growth path.
(3) The overall σ convergence shows a downward trend and the absolute β and relative β convergence confirm the existence of convergence trend. This indicates the phenomenon of catching up effect in eco-efficiency, but cities are going to stay in different eco-effficiency state in the end due to different developmental background. The results also show that economic growth, fiscal decentralization, and foreign direct investment increase eco-efficiency, while increased secondary industry causes a decline in eco-efficiency.

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