AIMS Mathematics, 9(5): 11660–11695.
DOI: 10.3934/math.2024572
Received: 26 February 2024
Revised: 15 March 2024
Accepted: 18 March 2024
Published: 26 March 2024

http://www.aimspress.com/journal/Math

Research article

Spatial convergence characteristics of low carbon economy and economic growth quality: based on Guangdong urban data

Xiangsong Ye[1], Longju Zhou[1] and Zhiyong Wang[2]

[1] School of Economics and Statistics, Guangzhou University, Guangzhou 510006, China
[2] The Research Center for Guangdong-Hong Kong-Macao Greater Bay Area, Guangdong University of Finance & Economics, Foshan 528100, China

Abstract: As China's economy transitions from a stage of high-speed growth to a stage of high-quality development, the concept of low-carbon and green economic development has gained increasing popularity. Mastering the regional differences and changing patterns of low-carbon economy and economic growth quality is an important prerequisite for further promoting low-carbon economic development and improving the quality of economic growth. Taking the data of 21 prefecture-level cities in Guangdong Province from 2008 to 2019 as examples, we calculated the low-carbon economy and the quality index of economic growth, and analyzed the convergences between them through coefficient of variation analysis and a panel data convergence model with fixed effects. The results showed that: First, the convergence of low-carbon economy was better than the convergence of economic growth quality. Second, the low-carbon economy of Guangdong Province had σ convergence, and the imbalance between regions of low-carbon economy was alleviated, but the quality of economic growth of Guangdong Province did not have σ convergence. Third, there was absolute and conditional β convergence in the quality of low-carbon economy and economic growth in Guangdong Province. Fourth, the convergence rate of low-carbon economy in Guangdong Province showed "club difference"; the same was true of σ convergence, absolute β convergence, conditional β convergence, and dimensional convergence of economic growth quality in various regions of Guangdong Province. The exploration conducted in this article was conducive to better grasping the changing patterns of low-carbon economy and economic growth quality, enriching relevant research. The conclusions of this paper can provide decision-making basis for China to formulate urban and regional economic policies, achieve high-quality economic development, and "double carbon goal".

Keywords: low carbon economy; quality of economic growth; convergence; new development

philosophy

Mathematics Subject Classification: 62H15, 62J05, 62P20, 91B76, 91B82

1. Introduction

As environment issues have been increasingly prominent, low carbon development has gradually been a needed option for the economic development of all countries. China is striving to foster its ecological progress, seeking high-quality development, and it has been stated that China's economy has been transitioning from a phase of high-speed growth to a stage of high-quality development. Economic growth has gone from emphasizing quantity to stressing quality, which shows the intrinsic requirements of keeping a sustainable and healthy economic growth in China. Since China is at the pivotal moment of promoting ecological progress and achieving high-quality development, the exploration and grasp of the changing regularities of low carbon economy and quality of economic growth is an important guarantee for successfully achieving high-quality development. The construction of the Guangdong-Hong Kong-Macao Greater Bay Area is a key strategic plan of China. The goal is to build it into a first-class bay area and a world-class urban agglomeration and thus set it as an example of high-quality development. As a vital part of the Guangdong-Hong Kong-Macao Greater Bay Area, Guangdong Province is one of the most economically and socially developed provinces in China; therefore, it must be at the forefront of the provinces in China in exploring and achieving high-quality economic development.

There is limited research on measuring low-carbon economy and quality of economic growth from the perspective of new development concepts, and further research is needed on the regional imbalance and its changing patterns of low-carbon economy and quality of economic growth. The convergence of low-carbon economy and quality of economic growth has been a new exploration direction in recent years, with a very broad space for expansion. The major innovations of this paper include: On the one hand, we construct low-carbon economy and quality of economic growth measurement indicators from the perspective of new development concepts, and adopt the entropy method for measurement; on the other hand, we use the coefficient of variation and convergent model with fixed effects to analyze the convergences of low carbon economy and quality of economic growth.

This paper is conducive to better grasping the changing regularities of low carbon economy, quality of economic growth and their convergences, enriching related research on low carbon economy and quality of economic growth, and providing a reference for the formulation of urban and regional economic policies. This provides the realization of high-quality economic development and "double carbon goal" of China.

The Kyoto Protocol, aiming to address climate changes, promoted the formation of the concept of low carbon economy, which was first proposed in the UK's Energy White Paper in 2003 [15]. Chinese scholars have also begun to discuss low carbon economy in the context of China's economic development model [6,16,19], and since then, most studies have discussed low carbon and high-quality development at the macro level [23,44,47,50]. Some research has studied how firms can achieve low carbon development at the micro level [38].

Quality of economic growth has a definition in both narrow and broad sense. In a narrow sense, it can be analyzed from perspectives of total factor productivity [30,49], economic structure [26,45],

and environment [17]. In a broad sense, which is widely recognized, scholars have begun to comprehensively analyze it from the aspects of the environment, income, welfare, education, law, and order [5,37]. The evaluation of quality of economic growth is developing in a multi-dimensional way. Also, different research needs to make the evaluation dimension subjective [27].

Some scholars put quality of economic growth into the theoretical framework of economic growth for analysis, and believed that it was an extension of the theoretical framework of economic growth and that quantitative growth and qualitative growth were two aspects of the same question in economic growth theory [33]. Ren's research team conducted in-depth discussions from this perspective [9,10,40], which had a broad impact on subsequent research. Therefore, most scholars regard in their research the quality of economic growth as a concept that is closely related to economic growth amount but has a broader connotation. In terms of measurement methods, by constructing a multi-dimensional indicator system, principal component analysis [10,21,40,48], and entropy method [41,42] are adopted to measure the quality of economic growth. The low carbon economy in economic growth quality has been a hot topic of concern in the academic community in recent years [20], with more and more related research focusing on different countries [2,12,22,28], a series of related studies have been conducted from different perspectives [51–57].

Early discussions on the phenomenon of economic growth convergence include the analysis of changes in per capita income within a neoclassical framework [32], and the "Yerkes-Dodson Law" in regional income convergence [43]. Since then, scholars have begun to carry out corresponding empirical research in line with local conditions [1,7]. Although some studies have also been questioned [14], they have played a great role in promoting relevant research. In the 1990s, scholars questioned the traditional empirical process and began to try new methods to empirically analyze the phenomenon of economic growth convergence [8,29,31]. Furthermore, scholars have also begun to explore the phenomenon of economic growth convergence in China [11,18,34], and influential representative results have emerged one after another, such as economic growth convergence mechanism based on the neoclassical analysis framework [3,4] and its empirical analysis [24,39], "club convergence" of China's economic growth [35]. In contrast, there are relatively few studies on the convergence of low carbon economy and quality of economic growth. In recent years, scholars have begun to try to analyze the convergence of quality of economic growth from different perspectives and with various methods [13,25,36,46], but it is at the early stage of exploration.

Most literatures have focused on the convergence of economic growth and income. Recently, scholars have begun to pay attention to the convergence of low-carbon economy and quality of economic growth, yet it is at the early stage of exploration, and there is a very broad space for expansion. As cities pay more and more attention to the quality of economic growth, how does their convergences of low carbon economy and quality of economic growth change? Based on the research status quo and the reality of urban economic development, we construct measurement indicators of low carbon economy and quality of economic growth in combination with the new development philosophy, and analyze the convergences in multiple dimensions.

2. Measurement of low carbon economy and quality of economic growth

2.1. Construction of the indicator system

The essence of low carbon economy is to realize the green development of economy. Thus,

green development indicators of quality of economic growth can be adopted to construct measurement indicators of low carbon economy (see Table 1). Therefore, the green dimension of quality of economic growth has reflected the low carbon development of economy. The secondary indicators are composed of coordination of energy efficiency and environmental pollution. Energy efficiency is shown by growth of energy consumption per unit of *GRP*, which is a negative indicator. Environmental pollution consists of four basic indicators, namely waste water discharge, industrial waste gas emission, industrial fume (dust) emission, and industrial solid waste production. In order to eliminate the biased error in the measurement of indicators, the indicators used here are relative indicators, which are all negative indicators. These indicators all have made energy efficiency and environmental pollution highly relative to GRP, which better shows the low carbon development of economy.

Table 1. Indicator system of low carbon economy.

Primary indicators	Secondary indicators	Basic indicators	Calculation methods	Unit	Indicator attribute
Green development dimension (Low carbon development)	energy efficiency	energy efficiency ($x11$)	growth of energy consumption per unit of GRP	%	negative
	environmental pollution	waste water discharge ($x12$)	total amount of waste water discharge/*GRP*	ton/ten thousand yuan	negative
		industrial waste gas emission ($x13$)	total amount of industrial waste gas emission/*GRP*	M^3/yuan	negative
		industrial fume (dust) emission ($x14$)	total amount of industrial smoke (dust) emission/*GRP*	ton/one hundred million yuan	negative
		industrial solid waste production ($x15$)	industrial solid waste production amount/*GRP*	ton/ten thousand yuan	negative

Many Chinese representative studies [10,33,40] have constructed indicator measurement systems of quality of economic growth, which involve some dimensions related to the new development philosophy, but few have constructed such system from the very five dimensions of the new development philosophy. Based on existing studies, we measured the quality of economic growth from the five dimensions of the new development philosophy, namely innovative, coordinated, green, open, and shared development dimensions. Quality of economic growth is first manifested in the transformation from traditional-factor-driven economic growth to innovation-driven economic growth and in the coordination within the economic system and among economic systems of different regions. Then, the external manifestation of the economic system is the coordinated development between humans and nature, as well as the linkage between domestic and international economies, whose ultimate goal is to widely share the final results. Table 2 is the indicator system of quality of economic growth with a total of 19 basic indicators.

Table 2. Indicator system of quality of economic growth.

Primary indicators	Secondary indicators	Basic indicators	Calculation methods	Unit	Indicator attribute
Innovative development dimension	R&D input	R&D intensity ($x1$)	total R&D spending/*GRP*	%	positive
		public budget on science and technology expenditure ($x2$)	public budget on science and technology expenditure/total public budget expenditure	%	positive
	R&D result	number of licensed patent ($x3$)		piece	positive
	Education input	public budget on education expenditure ($x4$)	public budget on education expenditure/total public budget expenditure	%	positive
Coordinated development dimension	coordination of industrial structure	proportion of the secondary industry ($x5$)		%	positive
		proportion of the tertiary industry ($x6$)		%	positive
	coordination of investment and consumption structure	investment rate($x7$)	gross capital formation/expenditure-based *GRP*	%	positive
		consumption rate ($x8$)	final consumption expenditure/expenditure-based *GRP*	%	positive
		investment-to-consumption ratio($x9$)	gross capital formation/final consumption expenditure		moderate
	coordination of urban and rural areas	urban-rural income ratio ($x10$)	per capita disposable income of urban residents/per capita disposable income of rural residents		negative
Green development dimension	energy efficiency	energy efficiency ($x11$)	growth of energy consumption per unit of GRP	%	negative
	environmental pollution	waste water discharge ($x12$)	total amount of waste water discharge/*GRP*	ton/ten thousand yuan	negative
		industrial waste gas emission ($x13$)	total amount of industrial waste gas emission/*GRP*	M^3/yuan	negative
		industrial fume (dust) emission ($x14$)	total amount of industrial smoke (dust) emission/*GRP*	ton/one hundred million yuan	negative
		industrial solid waste production ($x15$)	industrial solid waste production amount/*GRP*	ton/ten thousand yuan	negative
Open development dimension	opening structure	use of foreign capital ($x16$)	actual use of foreign capital/*GRP*	%	positive
		degree of dependence on foreign trade ($x17$)	total import and export volume/*GRP*	%	positive
Shared development dimension	regional sharing	regional income sharing level ($x18$)	per capita GRP at prefecture level/per capita GRP at provincial level	%	positive
	welfare change	per capita *GRP* ($x19$)		yuan	positive

The first dimension is the innovative development dimension. In this dimension, the secondary indicators are composed of R&D investment, R&D result, and education input. R&D investment has two basic indicators, R&D intensity and public budget on science and technology expenditure, which refer to the investment of R&D entities and the government's investment, respectively. The R&D result adopts the number of licensed patent as the basic indicator, which shows the output of R&D. Education input takes the proportion of education expenditure in the public budget as a basic

indicator, which reflects the potential of R&D.

The second dimension is the coordinated development dimension. In this dimension, the secondary indicators are composed of coordination of industrial structure, coordination of investment and consumption structure, and coordination of urban and rural areas. Coordination of industrial structure consists of the proportion of the secondary industry and the proportion of the tertiary industry. Coordination of investment and consumption structure consists of investment rate and consumption rate. For the two rates, the higher is not the better. Xiang [45] believes that it is more appropriate that the investment rate is lower than 38% and the consumption rate is higher than or equal to 60%. Based on this standard, it can be inferred that investment-to-consumption ratio should be lower than 63.3%. Therefore, investment rate and consumption rate are regarded as positive indicators, and investment-to-consumption ratio, a moderate indicator whose standard is lower than 63.3%, is utilized for adjustment. Coordination of urban and rural areas takes urban-rural income ratio as its basic indicator, which is a negative indicator and shown as "per capita disposable income of urban residents/per capita disposable income of rural residents".

The third dimension is the green development dimension, whose indicators are consistent with the previous ones of low carbon economy.

The fourth dimension is the open development dimension. In this dimension, the secondary indicator is composed of an opening structure. An opening structure consists of two basic indicators, namely the use of foreign capital and the degree of dependence on foreign trade, which reflect the concept of economic openness. The use of foreign capital is shown as "actual use of foreign capital/GRP", and the degree of dependence on foreign trade is represented as "total import and export volume/GRP".

The fifth dimension is the shared development dimension. In this dimension, the secondary indicators are composed of regional sharing and welfare change. According to Wei and Li [41,42], the regional income sharing level refers to the ratio of per capita *GRP* at a prefecture level to per capita *GRP* at a provincial level, and welfare change takes per capita *GRP* as its basic indicator.

2.2. Methods and data

2.2.1. Measurement method

In this paper, the entropy value method and the multi-objective linear weighted function method, which are commonly used in academia, are utilized to measure the quality of economic growth of cities in the Pearl River Delta. Specific steps are as follows:

The first step is to standardize the variables. The measurement indicator x_{ij} is standardized through the range method, which can eliminate the influence of quantity variance and dimension difference on the measurement indicator.

$$X_{ij} = \begin{cases} \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \ (\text{When } x_{ij} \text{ is a positive indicator}) \\ \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \ (\text{When } x_{ij} \text{ is a negative indicator}) \end{cases}. \quad (1)$$

In the above formulas, i represents city, j basic indicator, and x_{ij} and X_{ij} original basic indicator and standardized basic indicator respectively.

If the indicator is a moderate one, it should be standardized in line with the following reference

standards:

$$x_{ij} = \begin{cases} z_{ij} - z_0 \ (\text{when } z_{ij} > z_0, \text{the more } z_{ij} \text{ is greater than } z_0, \text{the better}) \\ z_0 - z_{ij} \ (\text{when } z_{ij} < z_0, \text{the more } z_{ij} \text{ is less than } z_0, \text{the better}) \end{cases}. \quad (2)$$

In these formulas, z_{ij} is a moderate indicator, and z_0 is the reference standard of a moderate indicator. The new transformed indicator should be standardized through the method of positive indicators as is shown in formula (1).

The second step is to calculate the information entropy E_j with standardized indicator X_{ij}.

$$E_j = -k \sum_{i=1}^{n} \left(\frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \ln \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \right). \quad (3)$$

In this formula, $k = 1/\ln(N)$. The data in this paper are all panel data, so N means the total number of samples.

The third step is to calculate the weight W_j of each basic indicator with the information entropy E_j.

$$W_j = \frac{(1-E_j)}{\sum_{j=1}^{m}(1-E_j)}. \quad (4)$$

In this formula, $1-E_j$ represents the information utility value of the jth indicator.

The fourth step is to calculate the quality of economic growth indicator *QEG* in the multi-objective linear weighted function.

$$QEG = \sum_{j=1}^{m} W_j X_{ij}. \quad (5)$$

The value range of the quality of economic growth indicator QEG is (0, 1), and the larger the value, the higher the quality of economic growth of the city.

2.2.2. Data resources

According to the research needs and data availability, we selected the data of various prefecture-level cities in Guangdong Province from 2008 to 2019, which are mainly from *China City Statistical Yearbook*, *Guangdong Statistical Yearbook*, and the Statistical Yearbook of various prefecture-level cities in Guangdong. For some missing data, they were replaced by the average value (or the mean) of calculations with the series mean method, the proximal point mean method, the proximal point median method, the linear interpolation method, and the linear trend method at certain points.

(1) Urban-rural income ratio. As for the coordination of urban-rural areas, the secondary indicator in coordinated development dimension, when calculating the urban-rural income ratio, the per capita rural income was also the per capita net income of rural residents in some areas before 2013. Since there was no relevant statistics on rural residents in Shenzhen, the urban-rural income ratio in Shenzhen was replaced by the average value of Guangdong Province from 2003 to 2013. After 2014, the Pearl River Delta has collected relevant data, and then the urban-rural income ratio in Shenzhen is replaced by the mean of the data of the Pearl River Delta from 2014 to 2019.

(2) Environmental pollution. Environmental pollution, the second indicator in green development dimension, consists of four basic indicators, namely waste water discharge, industrial waste gas emission, industrial fume (dust) emission, and industrial solid waste production. When it is

calculated, relative indicators are used in the measurement, that is, per unit (ten thousand yuan or yuan) *GRP* discharge or emission (ton or M^3).

(3) The sum of actual use of foreign capital and total import and export volume. When the basic indicators in open development dimension are measured and calculated, the sum of actual use of foreign capital and total import and export volume should be converted to Chinese yuan based on the average exchange rate for that year in Guangdong Province.

3. Convergence of quality of economic growth

3.1. σ convergence

The σ convergence of quality of economic growth (low carbon economy) refers to the trend that the gap of quality of economic growth (low carbon economy) between various regions gradually narrows over time, and it is usually measured by the coefficient of variation as follows[①]:

$$\sigma_{rt} = \frac{\sqrt{[\sum_{i=1}^{n_r}(QEG_{it} - \overline{QEG_{rt}})^2]/n_r}}{\overline{QEG_{rt}}}. \tag{6}$$

r refers to the region, and n_r represents the number of prefecture-level cities in r region. Coefficient of variation is the ratio of standard deviation to the mean of quality of economic growth (low carbon economy) indicator in the prefecture-level city of the region (r).

3.2. β convergence

The β convergence of quality of economic growth (low carbon economy) refers to the trend that the gap of growth rates of economic growth quality (low carbon economy) between various regions gradually narrows over time, and the β convergence model based on standard panel data model is as follows:

$$\ln(\frac{QEG_{i,t+1}}{QEG_{i,t}}) = \alpha + \beta \ln QEG_{it} + \delta X_{it} + \mu_i + \gamma_t + \varepsilon_{it}. \tag{7}$$

When δ=0, it is an absolute β convergence model; when $\delta \neq 0$, it is a conditional β convergence model. The government is regarded as an import factor that affects quality of economic growth (low carbon economy); therefore, it is defined as a major control variable. When β is significantly less than 0, convergence exists, and convergence rate is $\frac{-\ln(1+\beta)}{T}$. On the contrary, divergence exists.

3.3. Club convergence

The club convergence of quality of economic growth (low carbon economy) refers to the convergence of regions with similar characteristics. According to the division of economic regions in Guangdong Province in the *Guangdong Statistical Yearbook*, we divide economic regions in

[①] The variable is QEG when measuring quality of economic growth and is LCE when measuring low carbon economy, the same below.

Guangdong Province into the Pearl River Delta, the East Wing, the West Wing and the mountain area. According to Opinions on Constructing the New Development Pattern of "One Core, One Belt, One Area" and Promoting Coordinated Regional Development of Guangdong Province (July, 2019) issued by Guangdong Provincial Party Committee and the People's Government of Guangdong Province, this paper divides economic regions in Guangdong Province into One Core (the Pearl River Delta), One Belt (the coastal economic belt), and One Area (the northern ecological development area). The convergences of these "clubs" are analyzed separately.

3.4. Relevant variables and data description

It is difficult to directly observe governmental influence. However, the amount of fiscal expenditure reflects the ability of the government to regulate and intervene in the economy, so fiscal expenditure is chosen as a substitute variable for governmental influence. The relevant variable data is the data of various prefecture-level cities in Guangdong Province from 2008 to 2019, mainly collected from the *China City Statistical Yearbook*, *Guangdong Statistical Yearbook* and the statistical yearbooks of various prefecture-level cities. The descriptive statistics of the main variables of the model are shown in Table 3.

Table 3. Descriptive statistics of the main variables.

Variables	Meaning	Measured value	Mean	Standard deviation	Median	Minimum	Maximum
LCE(*D*3)	low carbon economy indicator (score in green development dimension)	231	0.0182	0.0029	0.0188	0.0063	0.0230
ln*LCE*	logarithm of low carbon economy indicator	231	-4.0229	0.1960	-3.9734	-5.0654	-3.7714
$\ln(\frac{LCE_{i,t+1}}{LCE_{i,t}})$	growth rate of low carbon economy	231	0.0257	0.0690	0.0157	-0.1870	0.4242
QEG	growth quality indicator	231	0.2242	0.1175	0.1650	0.0893	0.6832
ln*QEG*	logarithm of growth quality indicator	231	-1.6132	0.4716	-1.8015	-2.4155	-0.3810
$\ln(\frac{QEG_{i,t+1}}{QEG_{i,t}})$	growth rate of economic quality	231	0.0153	0.0564	0.0189	-0.2408	0.2447
*D*1	score in innovative development dimension	231	0.0536	0.0503	0.0317	0.0122	0.3601
*D*2	score in coordinated development dimension	231	0.0633	0.0125	0.0618	0.0368	0.1077
*D*4	score in open development dimension	231	0.0415	0.0371	0.0294	0.0005	0.1968
*D*5	score in shared development dimension	231	0.0475	0.0479	0.0225	0.0010	0.1869
lnPFE	public fiscal expenditure	231	5.4648	0.9156	5.3735	3.6225	8.4325

4. Convergence analysis of economic growth quality and low carbon economy

4.1. σ convergence analysis

4.1.1. *σ* convergence analysis of economic regions

The σ convergence of low carbon economy divided by economic regions of Guangdong Province is shown in Figure 1. From Figure 1, we can see that the σ convergence coefficient of the low carbon economy in the province is generally declining, indicating that σ convergence appears in the data of low carbon economy in the province, and the regional imbalance of the low carbon economy in the province tends to decrease. The σ convergence coefficients of low carbon economy in the Pearl River Delta, the East Wing and the mountain areas show an overall downward trend, and the σ convergence coefficient of the low carbon economy in the West Wing increases before the year of 2016, but also tends to decline since then, indicating that σ convergence appears in the data of the regions, and the regional imbalance of low carbon economy tends to decrease.

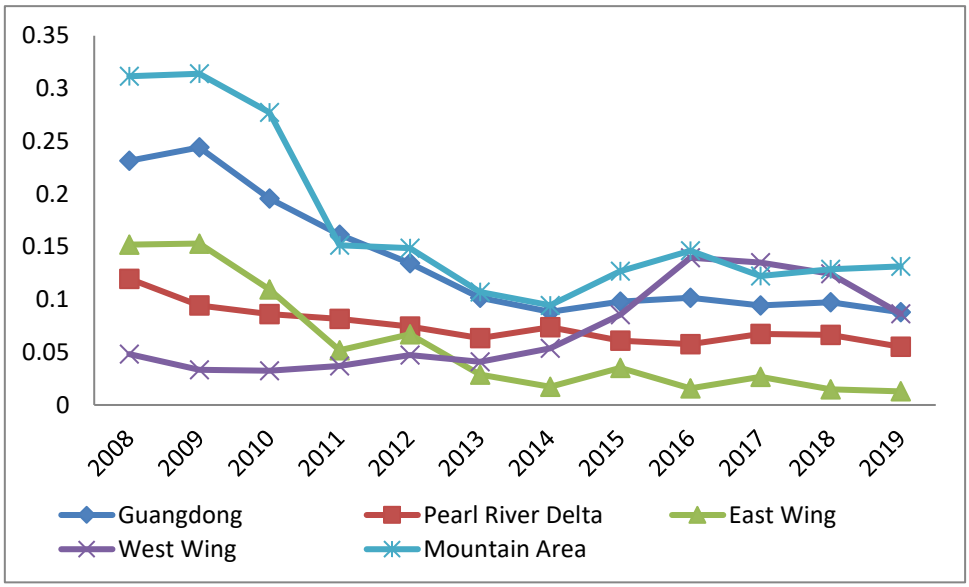

Figure 1. *σ* convergences of low carbon economy divided by economic regions in Guangdong Province.

Figure 2 showed the *σ* convergence of quality of economic growth various economic regions of Guangdong Province. It can be seen from Figure 2 that the overall *σ* convergence coefficient of quality of economic growth was on the rise, indicating that there was no *σ* convergence in the data of the province and that its regional imbalance in quality of economic growth was obvious. The overall *σ* convergence coefficient of the Pearl River Delta showed an upward trend, indicating that there was no *σ* convergence in the data of the Pearl River Delta and that its regional imbalance in quality of economic growth was obvious. Although the *σ* convergence coefficients in the East Wing and the mountain area increased slightly in some years, they showed a downward trend on the whole, indicating that *σ* convergence occurred in the data of both the East Wing and the mountain area and that the regional imbalance of quality of economic growth in the two regions tended to be improved.

The σ convergence coefficient in the data of the West Wing fluctuated greatly, and there was also a relatively large fluctuation from 2018 to 2019, indicating that there was no σ convergence in the data of the West Wing and that its regional imbalance in the quality of economic growth was obvious.

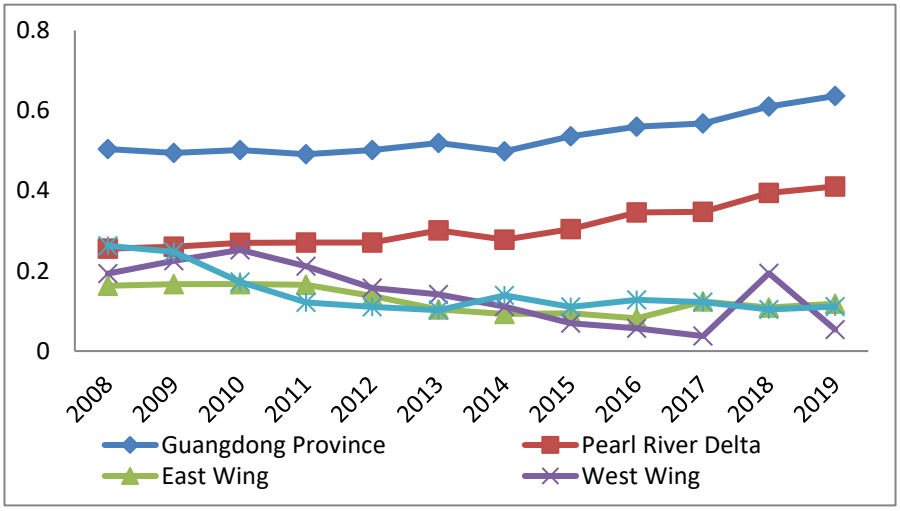

Figure 2. σ convergences of quality of economic growth various economic regions in Guangdong Province.

There was no σ convergence in the data of quality of economic growth of Guangdong Province, which meant the regional imbalance in quality of economic growth in the province was obvious. With further analysis of the σ convergences of the province's five dimensions (see Figure A1), the main reason should be that the regional imbalances in innovative, open, and shared development dimensions were quite obvious. In particular, the regional imbalance in innovative development dimension had a tendency to further expand. It can be explained that the gap between the Pearl River Delta and other regions tended to widen because the Pearl River Delta had more favorable conditions of agglomerating innovative elements than other regions. Figure A2 showed the trends of the mean of innovative development dimension in the Pearl River Delta and in the non-Pearl River Delta region and the gap between them. It is clear that the gap between the two regions continued to widen.

There was no σ convergence in the data of the Pearl River Delta, which meant the regional imbalance in quality of economic growth in the Pearl River Delta was obvious. With further analysis of the σ convergences of the five dimensions of the Pearl River Delta (see Figure A3), the main reason should be that the regional imbalances in innovative, open, and shared development dimensions were quite obvious. In particular, the regional imbalance of innovative development dimension had a trend to further expand. This may be because the gap between Guangzhou and Shenzhen and other regions in the Pearl River Delta tended to widen due to the favorable conditions of agglomerating innovative elements in Guangzhou and Shenzhen. Figure A4 showed the trends of the mean of innovative development dimension in Guangzhou and Shenzhen and in other regions in the Pearl River Delta and the gap between them. It is clear that the gap continued to widen.

Although the regional imbalance in quality of economic growth in the East Wing got slightly worse in some certain years, its overall situation tended to improve. With further analysis of the σ convergences of the five dimensions of the East Wing (see Figure A5), it can be concluded that

obvious regional imbalance in quality of economic growth appeared in the innovative, open, coordinated, and shared development dimensions in the East Wing. The regional imbalance in shared development dimension had the most obvious narrowing trend; and the regional imbalance in innovative and open development dimensions fluctuated greatly.

The regional imbalance in quality of economic growth in the West Wing was obvious and fluctuated greatly. With further analysis of the σ convergences of the five dimensions of the West Wing (see Figure A6), the main reason can be concluded that the regional imbalance in open development dimension was obvious and had a relatively high fluctuation while the regional imbalance in other four dimensions was not obvious and had a downward trend.

Although the regional imbalance in quality of economic growth in the mountain area got slightly worse in some certain years, its overall situation tended to improve. With further analysis of the σ convergences of the five dimensions of the West Wing (see Figure A7), it can be concluded that obvious regional imbalance in quality of economic growth appeared in innovative and open development dimensions in the West Wing. Moreover, the regional imbalance in innovative and open development dimensions had a relatively severe fluctuation; and the regional imbalance in shared development dimension had the most obvious narrowing trend.

4.1.2. σ convergence analysis of "One Core, One Belt, One Area"

The σ convergences of low carbon economy of regions divided into "One Core, One Belt, One Area" are shown in Figure 3. It can be seen from Figure 3 that the σ convergence coefficient of each region shows an overall downward trend, indicating that there is a σ convergence in the data of each region, and the regional imbalance of the low-carbon economy tends to narrow.

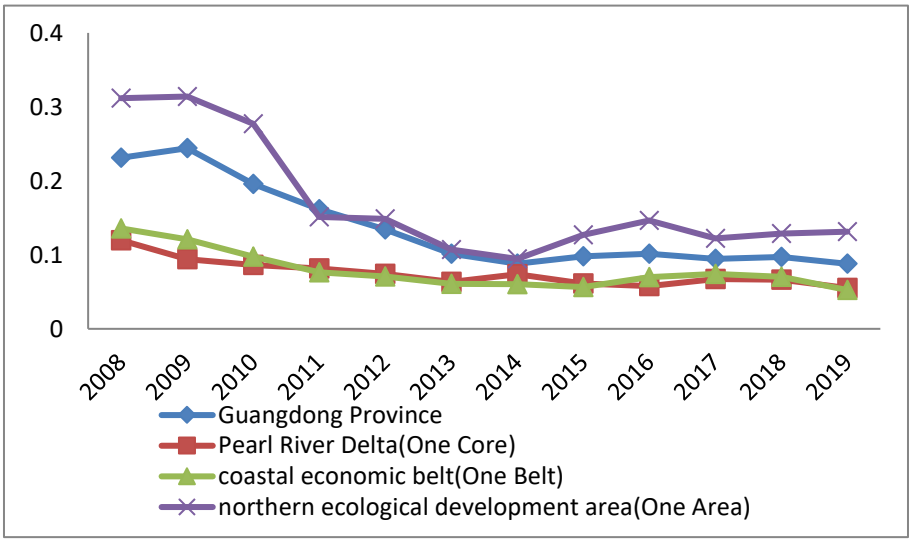

Figure 3. σ convergences of low carbon economy of regions divided into "One Core, One Belt, One Area".

The σ convergences of quality of economic growth of regions divided into "One Core, One Belt, One Area" are shown in Figure 4. It can be seen from Figure 4 that the σ convergence coefficient of the coastal economic belt generally showed an upward trend from 2008 to 2019, which meant there

was no σ convergence in the data of the coastal economic belt, and its regional imbalance in the quality of economic growth was obvious[①].

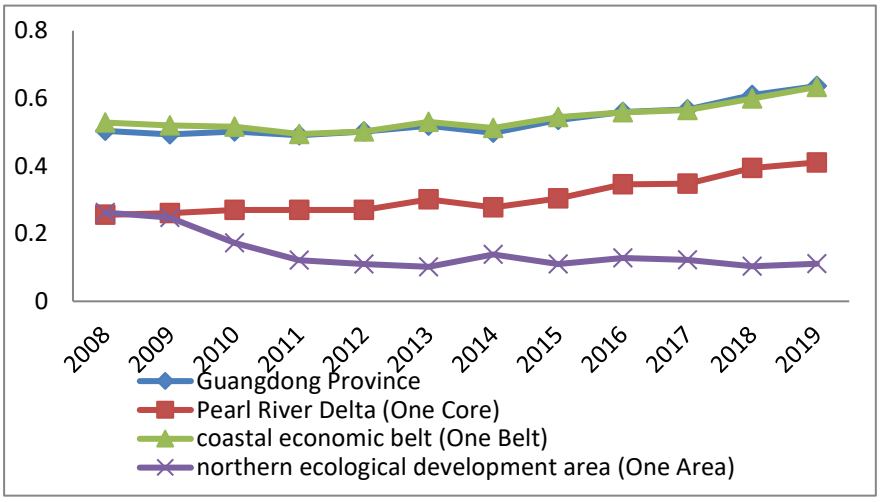

Figure 4. σ convergences of quality of economic growth of regions divided into "One Core, One Belt, One Area".

With further analysis of the σ convergences of the five dimensions of economic growth quality of the coastal economic belt (see Figure A8), the main reason for its regional imbalance in quality of economic growth should be that the regional imbalance in innovative, open, and shared development dimensions was quite obvious. In particular, the regional imbalance in innovative development dimension had a tendency to further expand. This might have the following reasons: First, the gap between the seven coastal cities in the Pearl River Delta and the East and West Wings tended to widen in innovative development dimension. Figure A9 showed the trends of the mean of innovative development dimension of the seven coastal cities in the Pearl River Delta and the East and West Wings. Second, in terms of the seven coastal cities in the Pearl River Delta, the gap between Guangzhou, Shenzhen, and the other five coastal cities in the Pearl River Delta tended to widen in innovative development dimension. Figure A10 showed the trend of the mean of innovative development dimension in Guangzhou, Shenzhen, and the other five coastal cities in the Pearl River Delta. Third, obvious imbalance also appeared in innovative development dimension in the East and West Wings. Figure A11 showed the trends of the mean of innovative development dimension in the East and West Wings, and from the figure, it can be seen that the gap between these two regions had a fluctuation and a growing trend as well.

4.2. β convergence analysis

4.2.1. Absolute β convergence analysis

Tables 4 and 5 showed the Hausman test results of the absolute β convergence model of low carbon economy, and from the x^2 value, it is more appropriate to choose the fixed effect model and

[①] "One Core" and "One Area" correspond to the Pearl River Delta and the mountain area respectively, which have been analyzed in previous part, so they are not analyzed in this part.

reject the null hypothesis that there is no systematic difference in coefficients (i.e., a_i is not correlated with x_{it}, and random effects model should be chosen) at a significant level of 1%. Table 4 shows the estimated results of absolute β convergence of low carbon economy of different economic regions. According to the estimated results, the β coefficients of the absolute convergence model of the province and the subregions are all negative, which is significant at the 1% level, indicating that there is absolute β convergence in the data of the province and the subregions, and the growth rate of the low carbon economy is gradually converging. Table 4 shows the estimated absolute β convergence of the low carbon economy of regions divided into the "One Core, One Belt, One Area", and from the estimated results, the β coefficient of the absolute convergence model of the coastal economic belt is negative, which is significant at the 1% level, indicating that there is absolute β convergence in the data of the coastal economic belt, and the growth rate of the low carbon economy is gradually converging.

Table 4. Estimated results of absolute β convergence model of low carbon economy (of various economic regions).

Variables	Guangdong Province	Pearl River Delta	East Wing	West Wing	Mountain area
β	-0.2329***	-0.2511***	-0.2138***	-0.3382***	-0.2304***
	(-7.3841)	(-5.3896)	(-5.0191)	(-2.8374)	(-3.3772)
Constants	-0.9114***	-0.9744***	-0.8278***	-1.3220***	-0.9245***
	(-7.1782)	(-5.3075)	(-4.8397)	(-2.8090)	(-3.2038)
Individual effects	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes
Hausman test	7.82***				
sigma_u	0.0195	0.0131	0.0053	0.0268	0.0207
sigma_e	0.0622	0.0245	0.0329	0.0430	0.1157
R^2	0.2069	0.2461	0.3924	0.2173	0.1888
N	231	99	44	33	55

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table 5. Estimated results of absolute β convergence model of low carbon economy (of "One Core, One Belt, One Area").

Variables	Guangdong Province	Pearl River Delta	Coastal economic belt	Northern ecological development area
β	-0.2329***	-0.2511***	-0.2316***	-0.2304***
	(-7.3841)	(-5.3896)	(-7.1835)	(-3.3772)
Constants	-0.9114***	-0.9744***	-0.8991***	-0.9245***
	(-7.1782)	(-5.3075)	(-7.0374)	(-3.2038)
Individual effects	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Hausman test	7.82***			
sigma_u	0.0195	0.0131	0.0120	0.0207
sigma_e	0.0622	0.0245	0.0307	0.1157
R^2	0.2069	0.2461	0.2707	0.1888
N	231	99	154	55

Note: Figures in parentheses are t statistics; Hausman test here refers to the x^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Tables 6 and 7 show the Hausman test results of the absolute β convergence model of quality of economic growth, and according to the results, it is more appropriate to choose the fixed effect model. Table 6 shows the estimated results of absolute β convergence of various economic regions in Guangdong. According to the estimated results, the β coefficient of the absolute convergence model of Guangdong Province was negative and significant at the 1% level, indicating that there was absolute β convergence in the data of the province and that the growth rates of economic quality gradually converged. The β coefficient of the absolute convergence model of the Pearl River Delta was insignificantly positive, indicating that there was no absolute β convergence in the data of the Pearl River Delta. The β coefficients of the absolute convergence models of the East Wing, the West Wing, and the mountain area were all negative and significant at the 5% level, indicating that there were absolute β convergences in the data of the East Wing, the West Wing, and the mountain area, and that the growth rates of economic quality gradually converged. Table 7 showed the estimated results of absolute β convergence of regions divided into "One Core, One Belt, One Area". The results showed that the β coefficients of the absolute convergence model of the coastal economic belt are all negative and significant at the 5% level, indicating that there is absolute β convergence in the data of the coastal economic belt and that the growth rates of economic quality gradually converged.

According to the estimated results of the five dimensions of quality of economic growth in Guangdong Province (see Table A1), the β coefficients of the absolute convergence model of the five dimensions were all negative and significant at the 1% level, indicating that there were absolute β convergences in the data of the five dimensions of Guangdong Province and that their growth rates of economic quality gradually converged. According to the estimated results of the five dimensions of quality of economic growth in the Pearl River Delta (see Table A2), the β coefficients of the absolute convergence model of the coordinated, green, and shared development dimensions were all negative and significant at the 1% level, and the β coefficient of the absolute convergence model of the innovative development dimension was negative and significant at the 10% level, which indicated that the growth rates of the innovative, coordinated, green, and shared development dimensions of the Pearl River Delta gradually converged. The β coefficient of the absolute convergence model of the open development dimension was insignificantly negative, indicating that there was no absolute convergence in the growth rate of the open development dimension of the Pearl River Delta.

According to the estimated results of the five dimensions of quality of economic growth in the East Wing (see Table A3), the β coefficients of the absolute convergence model of the innovative, coordinated, green (LCE), and shared development dimensions were negative and significant at the 1% level, indicating that the growth rates of economic quality of these four dimensions gradually converged. The β coefficient of the absolute convergence model of the open development dimension was insignificantly negative, indicating that there was no absolute convergence in the growth rate of the open development dimension of the East Wing. Moreover, according to the estimated results of the five dimensions of the West Wing (see Table A4), the β coefficients of the absolute convergence model of the five development dimensions were all negative. The β coefficient of the absolute convergence model was significant at the 5% level in the coordinated development dimension and at the 1% level in the other four dimensions, which indicated that the growth rates of economic quality of the five dimensions in West Wing gradually converged.

According to the estimated results of the five dimensions of quality of economic growth in the mountain area (see Table A5), the β coefficients of the absolute convergence model of the five

development dimensions were all negative. The β coefficient of the absolute convergence model was significant at the 5% level in the open development dimension and at the 1% level in the other four dimensions, which indicated that the growth rates of economic quality of the five dimensions in West Wing gradually converged. Furthermore, according to the estimated results of the five dimensions of the coastal economic belt (see Table A6), the β coefficients of the absolute convergence model of the five development dimensions were all negative and significant at the 1% level, which indicated that the growth rates of economic quality of the five dimensions in the coastal economic belt gradually converged.

Table 6. Estimated results of absolute β convergence model of quality of economic growth (of various economic regions).

Variables	Guangdong Province	Pearl River Delta	East Wing	West Wing	Mountain area
β	-0.1745***	0.0107	-0.3177***	-0.2269**	-0.3773***
	(-4.3876)	(0.2027)	(-3.0155)	(-2.2221)	(-4.4361)
Constants	-0.2663***	0.0307	-0.5972***	-0.4514**	-0.7226***
	(-4.1426)	(0.5089)	(-2.9565)	(-2.1130)	(-4.3814)
Individual effects	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes
Hausman test	20.69***				
sigma_u	0.0889	0.0189	0.0328	0.0192	0.0420
sigma_e	0.0539	0.0459	0.0416	0.0695	0.0578
R^2	0.0843	0.0005	0.1891	0.1455	0.2865
N	231	99	44	33	55

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table 7. Estimated results of absolute β convergence model of quality of economic growth (of "One Core, One Belt, One Area").

Variables	Guangdong Province	Pearl River Delta	Coastal economic belt	Northern ecological development area
β	-0.1745***	0.0107	-0.1202**	-0.3773***
	(-4.3876)	(0.2027)	(-2.5908)	(-4.4361)
Constants	-0.2663***	0.0307	-0.1647**	-0.7226***
	(-4.1426)	(0.5089)	(-2.3176)	(-4.3814)
Individual effects	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Hausman test	20.69***			
sigma_u	0.0889	0.0189	0.0679	0.0420
sigma_e	0.0539	0.0459	0.0507	0.0578
R^2	0.0843	0.0005	0.0461	0.2865
N	231	99	154	55

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

4.2.2. Conditional β convergence analysis

Tables 8 and 9 show the Hausman test results of the conditional β convergence model of low carbon economy. From the value of χ^2, it is more appropriate to choose a fixed-effect model to reject the null hypothesis that there is no systematic difference in coefficients at a significant level of 1%. Tables 8 and 9 show the conditional β convergence estimates categorized by economic regions and "One Core, One Belt, One Area", respectively. From the estimated results, the β coefficients of the provincial and regional conditional convergence models are negative, which is significant at the 1% level, indicating that there is a conditional β convergence in the data of Guangdong Province and the regions, and that the growth rate of the low carbon economy is gradually converging. According to the convergence rate formula, the convergence rate of Guangdong Province is 0.0364, the Pearl River Delta (One Core) 0.0703, the East Wing 0.0373, the West Wing 0.0443, the mountain area (One Area) 0.0721, and the coastal economic belt 0.0357.

Tables 10 and 11 show the Hausman test results of the conditional β convergence model of quality of economic growth. According to the results, it was more appropriate to choose the fixed-effect model. Table 10 showed the estimated results of conditional β convergence of regions divided into various economic regions. According to the estimated results, the β coefficient of the conditional convergence model of Guangdong Province was negative and significant at the 1% level, indicating that there was conditional β convergence in the data of the province and that the growth rates of economic quality gradually converged. The β coefficient of the conditional convergence model of the Pearl River Delta was insignificantly negative, indicating that there was no conditional β convergence in the data of the Pearl River Delta. The β coefficients of the conditional convergence models in the East Wing, West Wing, and the mountain area were all negative and significant at the 5% level, indicating that there was conditional β convergence in the East Wing, West Wing, and the mountain area and that their growth rates of economic quality gradually converged. According to the convergence rate formula, the convergence rates of Guangdong Province, the East Wing, the West Wing, and the mountain area were 0.0254, 0.0319, 0.0657, and 0.0500, respectively. Table 11 showed the estimated results of conditional β convergence of regions divided into "One Core, One Belt, One Area". According to the estimated results, the β coefficients of the conditional convergence model of the coastal economic belt were all negative and significant at the 1% level, indicating that there was conditional β convergence in data of the coastal economic belt and that the growth rates of economic quality gradually converged. According to the convergence rate formula, the convergence rate of the coastal economic belt was 0.0204.

According to the estimated results of quality of economic growth in the five dimensions of Guangdong Province (see Table A7), the β coefficients of the conditional convergence model of the five dimensions were all negative and significant at the 1% level, indicating that there was conditional β convergence in the data of the five dimensions of Guangdong Province and that their growth rates of economic quality gradually converged. The convergence rates of the five dimensions were 0.0376, 0.0584, 0.0364, 0.0634, and 0.0331, respectively. According to the estimated results of quality of economic growth in the five dimensions of the Pearl River Delta (see Table A8), the β coefficients of the conditional convergence model of the innovative, coordinated, green, and shared development dimensions were all negative and significant at the 1% level, indicating that their growth rates of economic quality gradually converged. The convergence rates of these four dimensions were 0.0320, 0.0516, 0.0703, and 0.0214, respectively. The β coefficient of the

conditional convergence model of the open development dimension was insignificantly negative, indicating that there was neither absolute β convergence nor conditional β convergence in quality of economic growth of the Pearl River Delta. With further analysis, the main reason why absolute and conditional β convergences did not appear in the data of the Pearl River Delta was that there was neither absolute β convergence nor conditional β convergence in the data of the open development dimension while they both appeared in the data of the other four dimensions. The advantages and conditions of opening to the outside world were quite different among the cities in the Pearl River Delta. Guangzhou and Shenzhen continued to expand their opening-up advantages by virtue of their favorable conditions. While Zhaoqing and Jiangmen also continued to expand their opening to the outside world, the speed of opening was difficult to catch up with that of Guangzhou and Shenzhen due to the limitations of basic conditions and geographical locations and some other reasons.

According to the estimated results of quality of economic growth in the five dimensions of the East Wing (see Table A9), the β coefficients of the conditional convergence model of the five dimensions were all negative and significant at the 1% level, indicating that there was conditional β convergence in the data of the East Wing and that the growth rates of economic quality of the five dimensions gradually converged. The convergence rates of the five dimensions were 0.1391, 0.0382, 0.0373, 0.1193, and 0.0404, respectively. Moreover, according to the estimated results of quality of economic growth in the five dimensions of the West Wing (see Table A10), the β coefficients of the conditional convergence model of the innovative, coordinated, green, and open development dimensions were negative and significant at the 1% level, indicating that the growth rates of economic quality of these four dimensions in West Wing gradually converged. The convergence rates of the four dimensions were 0.1533, 0.0533, 0.0443, and 0.1836, respectively. The β coefficient of the conditional convergence model of the shared development was insignificantly negative, indicating that there was no conditional convergence in the data of the shared development dimension in the West Wing.

According to the estimated results of quality of economic growth in the five dimensions of the mountain area (see Table A11), the β coefficients of the conditional convergence model of the five development dimensions were all negative and significant at the 1% level, indicating that there was conditional β convergence in the data of the mountain area and that their growth rates gradually converged. The convergence rates of the five dimensions were 0.0583, 0.0759, 0.0721, 0.0575, and 0.0430, respectively. Furthermore, according to the estimated results of quality of economic growth in the five dimensions of the coastal economic belt (see Table A12), the β coefficients of the conditional convergence model of the five development dimensions were all negative and significant at the 1% level, indicating that there was conditional β convergence in the data of the coastal economic belt and that their growth rates gradually converged. The convergence rates of the five dimensions were 0.0435, 0.0340, 0.0357, 0.1058, and 0.0332, respectively.

Table 8. Estimated results of conditional β convergence model of low carbon economy (of various economic regions).

Variables	Guangdong Province	Pearl River Delta	East Wing	West Wing	Mountain area
β	-0.3302***	-0.5385***	-0.3366***	-0.3857**	-0.5474***
	(-7.4553)	(-6.9107)	(-3.5979)	(-2.6611)	(-4.4519)
ln*PFE*	0.0349***	0.0383***	0.0301	0.0104	0.1599***
	(3.0686)	(4.3971)	(1.4694)	(0.5898)	(3.0061)
Constants	-1.4937***	-2.3381***	-1.4676***	-1.5629**	-3.0765***
	(-6.5815)	(-6.6362)	(-3.1434)	(-2.4918)	(-4.0257)
Individual effects	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes
Hausman test	15.72***				
sigma_u	0.0303	0.0146	0.0071	0.0275	0.0848
sigma_e	0.0609	0.0223	0.0325	0.0435	0.1073
R^2	0.2413	0.3819	0.4251	0.2269	0.3173
N	231	99	44	33	55
Convergence rate	0.0364	0.0703	0.0373	0.0443	0.0721

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table 9. Estimated results of conditional β convergence model of low carbon economy (of "One Core, One Belt, One Area").

Variables	Guangdong Province	Pearl River Delta	Coastal economic belt	Northern ecological development area
β	-0.3302***	-0.5385***	-0.3250***	-0.5474***
	(-7.4553)	(-6.9107)	(-6.6772)	(-4.4519)
ln*PFE*	0.0349***	0.0383***	0.0186**	0.1599***
	(3.0686)	(4.3971)	(2.5246)	(3.0061)
Constants	-1.4937***	-2.3381***	-1.3724***	-3.0765***
	(-6.5815)	(-6.6362)	(-6.0854)	(-4.0257)
Individual effects	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Hausman test	15.72***			
sigma_u	0.0303	0.0146	0.0128	0.0848
sigma_e	0.0609	0.0223	0.0301	0.1073
R^2	0.2413	0.3819	0.3029	0.3173
N	231	99	154	55
Convergence rate	0.0364	0.0703	0.0357	0.0721

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table 10. Estimated results of the conditional β convergence model of quality of economic growth (of various economic regions).

Variables	Guangdong Province	Pearl River Delta	East Wing	West Wing	Mountain area
β	-0.2436***	-0.0694	-0.2963**	-0.5144**	-0.4231***
	(-5.1577)	(-1.0082)	(-2.5859)	(-2.5889)	(-4.8011)
ln*PFE*	0.0219***	0.0227*	-0.0065	0.0758	0.0251
	(2.6258)	(1.7799)	(-0.5041)	(1.6693)	(1.6445)
Constants	-0.4975***	-0.1975	-0.5247**	-1.4451**	-0.9393***
	(-4.5851)	(-1.3974)	(-2.1022)	(-2.2926)	(-4.4961)
Individual effects	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes
Hausman test	30.23***				
sigma_u	0.1082	0.0250	0.0307	0.0916	0.0518
sigma_e	0.0532	0.0453	0.0420	0.0674	0.0568
R^2	0.1137	0.0352	0.1945	0.2228	0.3246
N	231	99	44	33	55
Convergence rate	0.0254		0.0319	0.0657	0.0500

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table 11. Estimated results of the conditional β convergence model of quality of economic growth (of "One Core, One Belt, One Area").

Variables	Guangdong Province	Pearl River Delta	Coastal economic belt	Northern ecological development area
β	-0.2436***	-0.0694	-0.2008***	-0.4231***
	(-5.1577)	(-1.0082)	(-3.1038)	(-4.8011)
ln*PFE*	0.0219***	0.0227*	0.0199*	0.0251
	(2.6258)	(1.7799)	(1.7736)	(1.6445)
Constants	-0.4975***	-0.1975	-0.3989***	-0.9393***
	(-4.5851)	(-1.3974)	(-2.6647)	(-4.4961)
Individual effects	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Hausman test	30.23***			
sigma_u	0.1082	0.0250	0.0959	0.0518
sigma_e	0.0532	0.0453	0.0503	0.0568
R^2	0.1137	0.0352	0.0673	0.3246
N	231	99	154	55
Convergence rate	0.0254		0.0204	0.0500

Note: Figures in parentheses are t statistics; Hausman test here refers to the χ^2 value of Hausman test; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

4.3. Analysis of club convergence

From the above analysis, some obvious differences between the "clubs" can be summarized as follows:

The first difference is in σ convergence. In terms of various economic regions, σ convergence appears in the data of both the East Wing and the mountain area, and the regional imbalance in quality of economic growth tends to be improved. On the contrary, σ convergence appears neither in the data of the Pearl River Delta nor in the data of the West Wing, and the regional imbalance in quality of economic growth in these regions is obvious. In particular, the σ convergence coefficient of the West Wing fluctuates greatly. In terms of "One Core, One Belt, One Area", σ convergence appears in the data of the northern ecological development area, and the regional imbalance of quality of economic growth tends to be improved. On the contrary, σ convergence appears neither in the data of the core region nor in the data of the coastal economic belt, and the regional imbalance of quality of economic growth is obvious. In terms of the five dimensions, each dimension varies greatly in all regions.

The second difference lies in β convergence. "Club difference" exists in convergence rates of low carbon economy of all regions mentioned. Regarding quality of economic growth, in the Pearl River Delta, there is no absolute β convergence or conditional β convergence. In the East Wing, the West Wing, and the mountain area, there are both absolute β convergence and conditional β convergence, and their growth rates of economic quality gradually converge. Their convergence rates are 0.0319, 0.0657, and 0.0500, respectively, and "club difference" shows in the convergence rates. In the coastal economic belt and the northern ecological development area, there are both absolute β convergence and conditional β convergence, and their growth rates of economic quality gradually converge. Their convergence rates are 0.0204, and 0.0500, respectively, and "club difference" shows in the convergence rates. From the perspective of the five dimensions, in the open development dimension, absolute convergence appears neither in data of the Pearl River Delta nor in the data of the East Wing, and no conditional convergence appears in the data of the Pearl River Delta; and in the shared development dimension, no conditional convergence appears in the data of the West Wing.

5. Conclusions

Based on the samples of 21 prefecture-level cities in Guangdong Province, we adopt the entropy method to measure the quality of economic growth, and analyze the coefficient of variation and panel data convergence model with fixed effects.

Our major findings are as follows:

(1) Convergence of low carbon economy performs better than that of quality of economic growth.

(2) Low carbon economy of Guangdong Province shows a σ convergence tendency, and the regional imbalance in low carbon economy tends to be alleviated. There is no σ convergence in quality of economic growth of Guangdong Province, and the regional imbalance in quality of economic growth in the province is obvious. In terms of quality of economic growth of different regions, σ convergence appears in the data of the East Wing and the mountain area (northern ecological development area), not in the data of the Pearl River Delta (core region), the West Wing,

or the coastal economic belt ("One Belt"); and especially in the West Wing, the σ convergence coefficient of the West Wing fluctuates greatly. In terms of quality of economic growth in the five dimensions, each dimension varies greatly in all regions.

(3) There are both absolute and conditional β convergences in low carbon economy and quality of economic growth of Guangdong Province. Also, the quality of economic growth in all the five dimensions appear absolute and conditional β convergences. In terms of quality of economic growth of different regions, no absolute β convergence or conditional β convergence appears in the data of the Pearl River Delta (core region), and there is no absolute or conditional β convergence in the data of the open development dimension. Absolute and conditional β convergences appear in the data of the East Wing, the West Wing, the mountain area (northern ecological development area), and the coastal economic belt. Except that there is no absolute β convergence in the data of the open development dimension of the East Wing, and no conditional β convergence in the data of the shared development dimension of the West Wing, absolute and conditional β convergences appear in the data of the other four dimensions of the East Wing, the West Wing, the mountain area (northern ecological development area), and the coastal economic belt.

(4) "Club difference" exists in convergence rates of low carbon economy of all regions mentioned. "Club difference" shows in the σ convergence, absolute β convergence, conditional β convergence, and five-dimensional convergence of quality of economic growth in various regions in Guangdong Province. This paper helps to better grasp the changing regularities of low carbon economy, quality of economic growth and their convergences, enrich related research, and provide reference for the formulation of urban and regional economic policies and the realization of high-quality economic development and "double carbon goal" of China.

The major implications are as follows: First, when seeking development, attention should be given to the overall and balanced improvement of the low carbon economy (green development) and for four dimensions, namely innovative, coordinated, open, and shared development, and importance should be attached to the balanced development of the five dimensions so as to achieve the comprehensive improvement of quality of economic growth. Second, the regional imbalance in quality of economic growth should be prevented, and the imbalance in quality of economic growth among regions should be gradually reduced in order to achieve coordinated development and enhance the overall quality and comprehensive competitiveness of the economy in Guangdong Province. Third, providing the actual situation in Guangdong Province, the gap between the Pearl River Delta and other regions in Guangdong Province needs to be narrowed, and so does the gap between the different areas within the Pearl River Delta, the East Wing, the West Wing, the mountain area (the northern ecological development area), and the coastal economic belt.

Use of AI tools declaration

The authors declare that they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. O. M. Amos, Unbalanced regional growth and regional income inequality in the latter stages of development, *Reg. Sci. Urban Econ.*, **18** (1988), 549–566. https://doi.org/10.1016/0166-0462(88)90026-9
2. I. Ayodele, M. O. Obaika, A. C. Munem, Does industrialization trigger carbon emissions through energy consumption? Evidence from OPEC countries and high industrialised countries, *Quant. Financ. Econ.*, **7** (2023), 165–186. https://doi.org/10.3934/QFE.2023009
3. R. J. Barro, X. Sala-I-Martin, Convergence across states and regions, *Brookings Papers on Econ. Activity*, (1991), 107–158. https://doi.org/10.2307/2534639
4. R. J. Barro, X. Sala-I-Martin, Convergence, *J. Polit. Econ.*, **100** (1992), 223–251. https://doi.org/10.1086/261816
5. R. J. Barro, Quantity and quality of economic growth, *Working Papers from Central Bank of Chile*, **5** (2002), 17–36.
6. J. Q. Bao, Y. Miao, F. Chen, Low carbon economy: revolution in the way of human economic development, *China Indust. Econ.*, 2008, 153–160. https://doi.org/10.19581/j.cnki.ciejournal.2008.04.018
7. W. Baumol, Productivity, growth, convergence and welfare: what the long-run data show, *Amer. Econ. Rev.*, **76** (1986), 1072–1085. https://doi.org/10.2307/1816469
8. A. Bernard, S. Durlauf, Convergence in international output, *J. Appl. Econ.*, **10** (1995), 97–108. https://doi.org/10.2307/2284967
9. X. J. Chao, K. Hui, Measuring quality of economic growth of China, *J. Quant. Tech. Econ.*, **26** (2009), 75–86.
10. X. J. Chao, B. P. Ren, The fluctuation and regional difference of quality of economic growth in China, *Econ. Res. J.*, **46** (2011), 26–40.
11. J. Chen, B. M. Fleisher, Regional income inequality and economic growth in China, *J. Comp. Econ.*, **22** (1996), 141–164. https://doi.org/10.1006/jcec.1996.0015
12. S. Chen, Designing the nationwide emission trading scheme in China, *Green Financ.*, **5** (2023), 431–451. https://doi.org/10.3934/GF.2023017
13. E. M. Chu, Y. J. Ma, Dynamic change and convergence test of regional economic growth quality: from the view of TFP growth, *J. Xiangtan Univ. (Philos. Soc. Sci.)*, **38** (2014), 20–25. https://doi.org/10.13715/j.cnki.jxupss.2014.01.005
14. B. Delong, Productivity, growth, convergence and welfare: comment, *Amer. Econ. Rev.*, **78** (1988), 1138–1154.
15. UK Department Trade, *Energy white paper: our energy future-creating a Low carbon economy*, London: DTI, 2003.
16. Y. Fu, Y. H. Ma, Y. J. Liu, W. Y. Niu, Development patterns of low carbon economy, *China Popul. Resour. Environ.*, **3** (2008), 14–19.
17. Q. H. Huang, M. Gao, Effects of environmental regulation on the quantity and quality of economic growth: based on the examination of simultaneous equation, *Economist*, **4** (2016), 53–62. https://doi.org/10.16158/j.cnki.51-1312/f.2016.04.007
18. T. Jian, J. D. Sachs, A. M. Warner, Trends in regional inequality in China, *China Econ. Rev.*, **7** (1996), 1–21. https://doi.org/10.1016/S1043-951X(96)90017-6

19. L. Q. Jin, R. Liu, Low-carbon economy and transformation of China's economic development model, *Inquiry Econ. Issues*, **1** (2009), 84–87.
20. C. M. Juan, S. Amparo, Cost and performance of carbon risk in socially responsible mutual funds, *Quant. Financ. Econ.*, **7** (2023), 50–73. https://doi.org/10.3934/QFE.2023003
21. Y. Y. Li, F. X. Lu, Spatial pattern of economic growth quality in Henan Province, *Econ. Geogr.*, **36** (2016), 41–47. https://doi.org/10.15957/j.cnki.jjdl.2016.03.006
22. Z. Li, Z. Huang, Y. Su, New media environment, environmental regulation and corporate green technology innovation: evidence from China, *Energy Econ.*, **119** (2023), 106545. https://doi.org/10.1016/j.eneco.2023.106545
23. B. Q. Lin, China's high-quality economic growth in the process of carbon neutrality, *Econ. Res. J.*, **1** (2022), 56–71.
24. Q. Liu, An analysis on convergence of economic growth in China, *Econ. Res. J.*, **6** (2001), 70–77.
25. S. Liu, Research on the regional differences in decomposition and convergence mechanism of economic quality in China, *J. Quant. Tech. Econ.*, **36** (2019), 24–41. https://doi.org/10.13653/j.cnki.jqte.20190906.001
26. Y. N. Liu, L. R. An, T. L. Jin, Quality of economic growth of China under the background of imbalanced economic structure, *J. Quant. Tech. Econ.*, **31** (2014), 20–35. https://doi.org/10.13653/j.cnki.jqte.2014.02.002
27. Z. B. Liu, Strengthening the real economy, promoting high-quality development, *Rev. Indust. Econ.*, **2** (2018), 5–9. https://doi.org/10.19313/j.cnki.cn10-1223/f.2018.02.001
28. S. Mark, International cooperation on climate research and green technologies in the face of sanctions: the case of Russia, *Green Financ.*, **5** (2023), 102–153. https://doi.org/10.3934/GF.2023006
29. L. Mauro, E. Godrecca, The case of Italian regions: convergence or dualism, *Econ. Notes*, **23** (1994), 447–472.
30. L. Mei, Z. Chen, The convergence analysis of regional growth differences in China: the perspective of the quality of economic growth, *J. Serv. Sci. Manage.*, **9** (2016), 453–476. https://doi.org/10.4236/jssm.2016.96049
31. P. Pagano, On productivity convergence in the European Community countries: 1950–1988, *Giornale Econ. Ann. Econ.*, **52** (1993), 389–401.
32. E. Ramsey, A mathematical theory of Saving, *Econ. J.*, **38** (1928), 543–559. https://doi.org/10.2307/2224098
33. B. P. Ren, The quality of economic growth: extension of economic growth theoretical framework, *Econ. Perspect.*, **11** (2013), 45–51.
34. H. Shen, The convergence analysis on regional economy inequality in China, *J. Quant. Tech. Econ.*, **8** (1999), 55–57.
35. K. R. Shen, J. Ma, The characteristics of "club convergence" of China's economic growth and its cause, *Econ. Res. J.*, **1** (2002), 33–39.
36. B. Shi, B. P. Ren, Strategic competition, spatial effects and the convergence of economic growth in China, *Econ. Perspect.*, **2** (2019), 47–62.
37. V. Thomas, M. Dailimi, A. Dhareshwar, D. Kaufmann, N. Kishor, R. Lopez, et al., *The quality of growth*, Oxford University Pross, 2000. https://doi.org/10.1596/0-1952-1593-1

38. J. M. Tu, X. Y. Li, Z. C. Guo, Enterprise carbon budget concept embedded in comprehensive budget system under the background of low-carbon economy, *China Ind. Econ.*, **3** (2014), 147–160. https://doi.org/10.19581/j.cnki.ciejournal.2014.03.012
39. H. K. Wei, Regional economic growth and its convergence in China, *China Collect. Econ.*, **3** (1997), 31–37. https://doi.org/10.19581/j.cnki.ciejournal.1997.03.006
40. J. Wei, B. P. Ren, Measuring and ordering the index of the quality of economic growth in China, *Econ. Perspect.*, **4** (2012), 27–33.
41. M. Wei, S. H. Li, Construction and measurement of China's economic growth index system under new normal conditions, *Economist*, **4** (2018), 19–26. https://doi.org/10.16158/j.cnki.51-1312/f.2018.04.004
42. M. Wei, S. H. Li, Study on the measurement of economic high-quality development level in China in the new era, *J. Quant. Tech. Econ.*, **35** (2018), 3–20. https://doi.org/10.13653/j.cnki.jqte.2018.11.001
43. J. G. Williamson, Regional inequality and the process of national development: a description of the patterns, *Econ. Dev. Cult. Change*, **13** (1965), 1–84.
44. C. X. Wu, Research on the synergistic effect of low-carbon economy in China, *J. Manage. World*, **37** (2021), 105–117. https://doi.org/10.19744/j.cnki.11-1235/f.2021.0110
45. J. B. Xiang, Measurement and analysis of China's economy structure imbalance, *J. Manage. World*, **9** (2008), 1–11. https://doi.org/10.19744/j.cnki.11-1235/f.2008.09.001
46. P. Xiao, L. Y. Li, J. Su, The measure of the quality of economic growth in China and its convergence analysis, *Theory Practice Financ. Econ.*, **37** (2016), 111–117. https://doi.org/10.16339/j.cnki.hdxbcjb.2016.04.017
47. Z. Xu, S. J. Zuo, S. H. Ding, High-quality development enabled by carbon peak and carbon neutralization: internal logic and implementation path, *Economist*, **11** (2021), 62–71. https://doi.org/10.16158/j.cnki.51-1312/f.2021.11.008
48. Y. Zeng, F. Han, J. F. Liu, Does the agglomeration of producers services promote the quality of urban economic growth? *J. Quant. Tech. Econ.*, **36** (2019), 83–100. https://doi.org/10.13653/j.cnki.jqte.2019.05.005
49. C. Zhang, J. Kong, Effect of equity in education on the quality of economic growth: evidence from China, *Int. J. Human Sci.*, **7** (2010), 47–69.
50. G. Y. Zhuang, Z. G. Zhou, Theoretical connotation and practical path of high-quality construction of low-carbon cities, *J. Beijing Univ. Tech. (Soc Sci. Ed.)*, **18** (2018), 30–39.
51. T. Li, X. Li, G. Liao, Business cycles and energy intensity: evidence from emerging economies, *Borsa Istanb. Rev.*, **22** (2022), 560–570. https://doi.org/10.1016/j.bir.2021.07.005
52. Z. Li, H. Chen, B. Mo, Can digital finance promote urban innovation? evidence from China, *Borsa Istanb. Review*, **23** (2022), 285–296. https://doi.org/10.1016/j.bir.2022.10.006
53. Y. Huang, K. Yu, C. Huang, Green finance engagement: an empirical study of listed companies on Chinese main board, *Green Financ.*, **5** (2023), 1–17. https://doi.org/10.3934/GF.2023001
54. V. M. Ribeiro, Green bond market boom: did environmental, social and governance criteria play a role in reducing health-related uncertainty? *Green Financ.*, **5** (2023), 18–67. https://doi.org/10.3934/GF.2023002
55. Q. Shen, Y. Zhang, J. Xiao, X. Dong, Z. Lin, Research of daily stock closing price prediction for new energy companies in China, *Data Sci. Financ. Econ.*, **3** (2023), 14–29. https://doi.org/10.3934/DSFE.2023002

56. F. Antolini, F. G. Truglia, Using farmhouse and food to enforce a tourism sustainable development model: empirical evidence from Italy, *Natl. Account. Rev.*, **5** (2023), 159–173. https://doi.org/10.3934/NAR.2023010
57. Y. Liu, L. Chen, H. Luo, Y. Liu, Y. Wen, The impact of intellectual property rights protection on green innovation: a quasi-natural experiment based on the pilot policy of the Chinese intellectual property cour, *Math. Biosci. Eng.*, **21** (2024), 2587–2607. https://doi.org/10.3934/mbe.2024114

Appendix

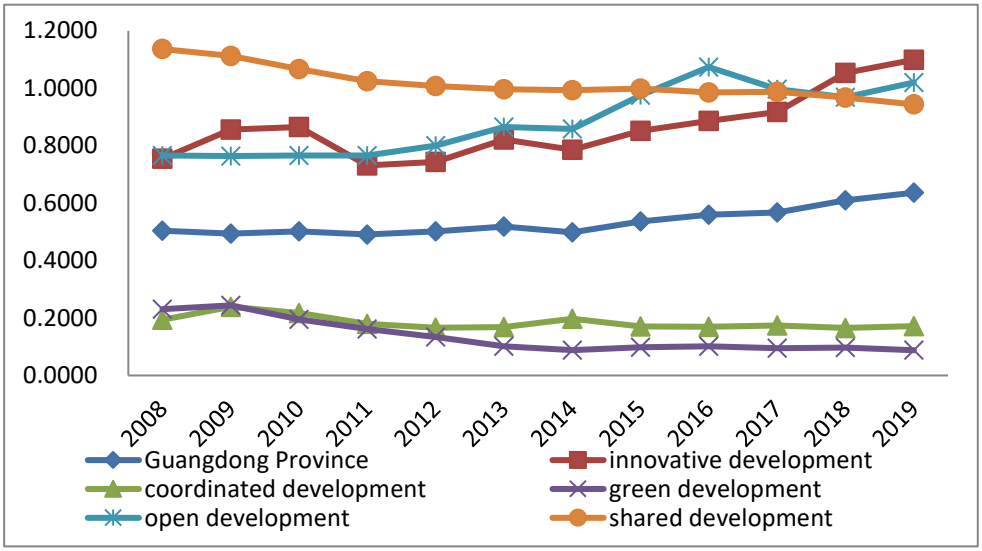

Figure A1. σ convergences of the five dimensions of quality of economic growth of Guangdong Province.

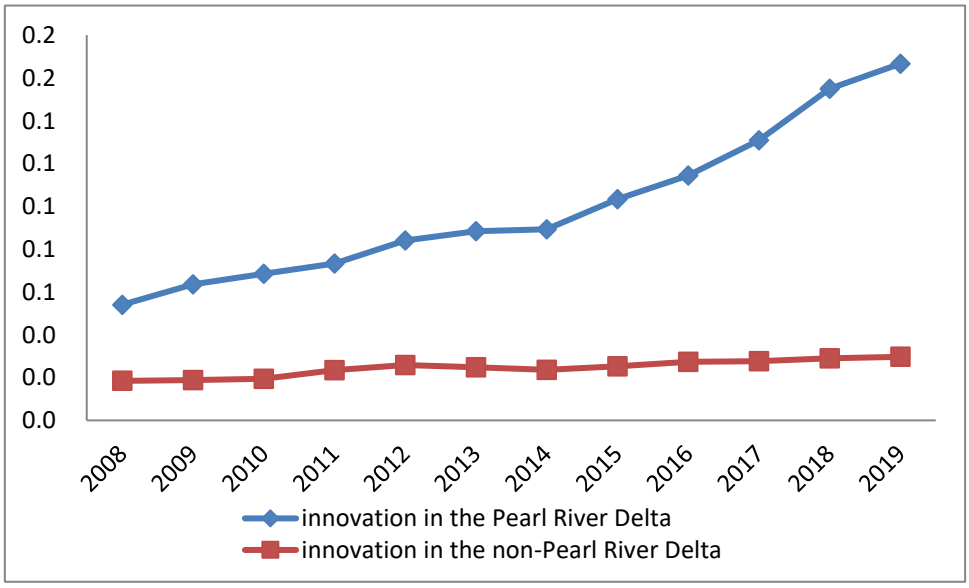

Figure A2. Innovation gap between the Pearl River Delta and the non-Pearl River Delta region.

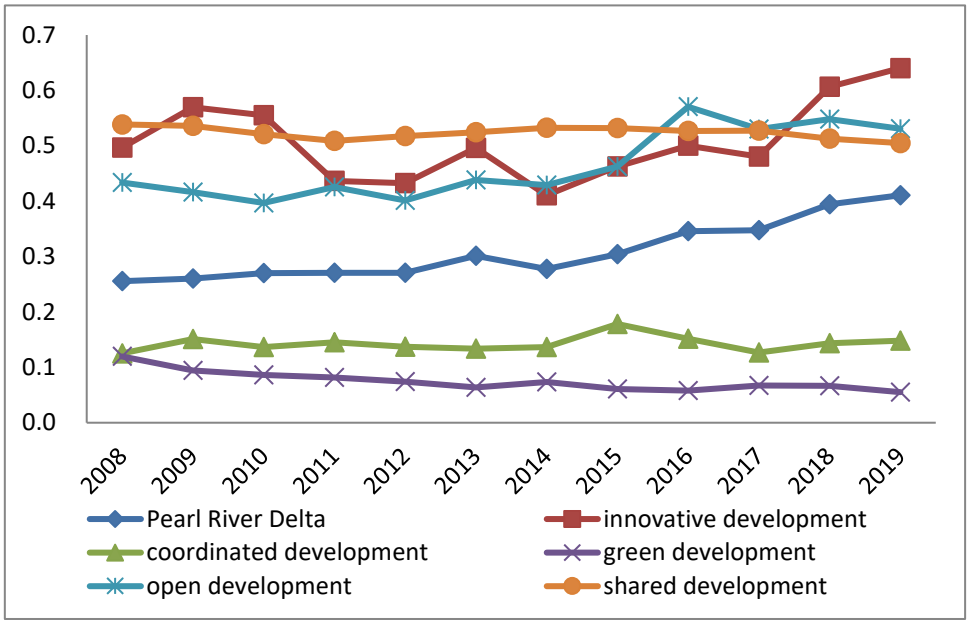

Figure A3. σ convergences of the five dimensions of quality of economic growth of the Pearl River Delta.

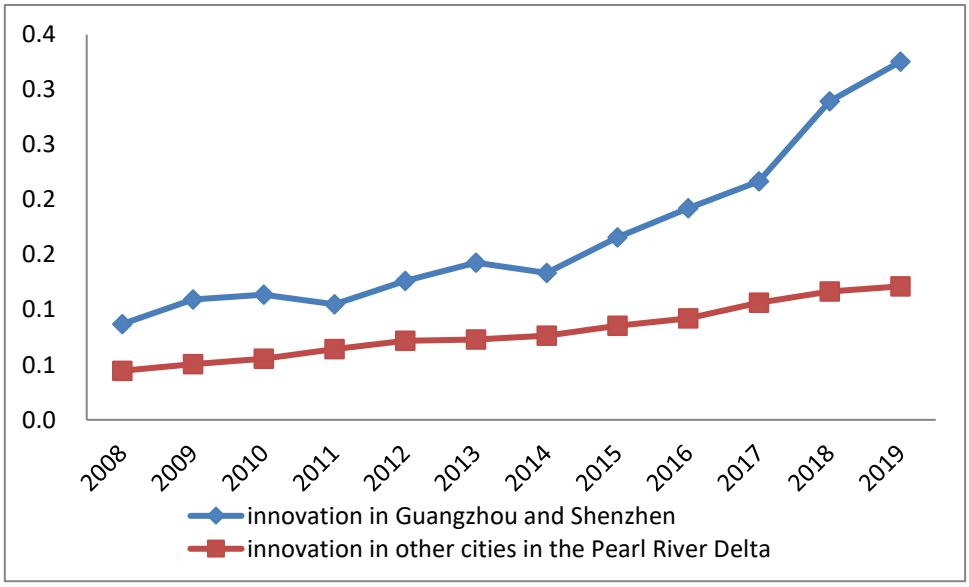

Figure A4. Innovation gap between Guangzhou and Shenzhen and other regions in the Pearl River Delta.

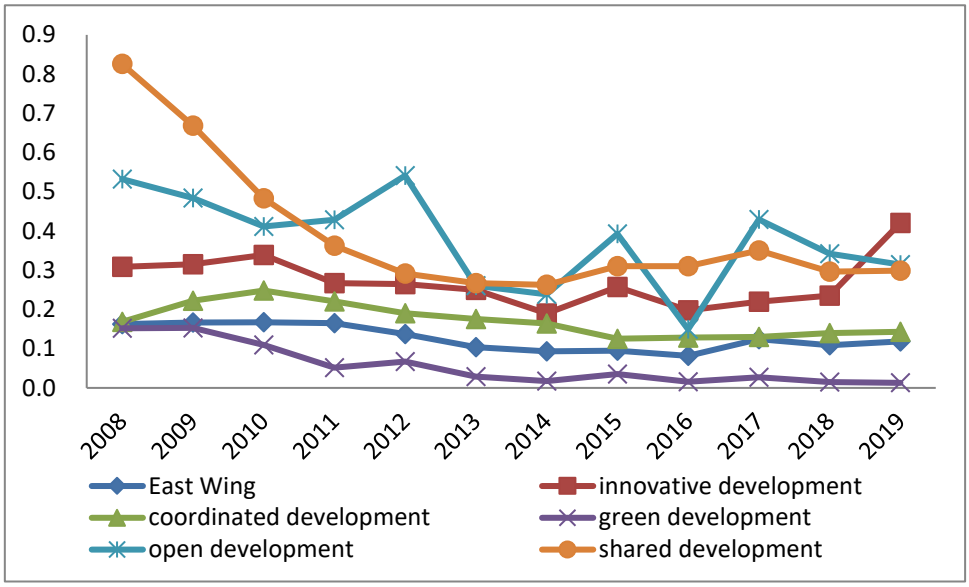

Figure A5. σ convergences of the five dimensions of quality of economic growth of the East Wing.

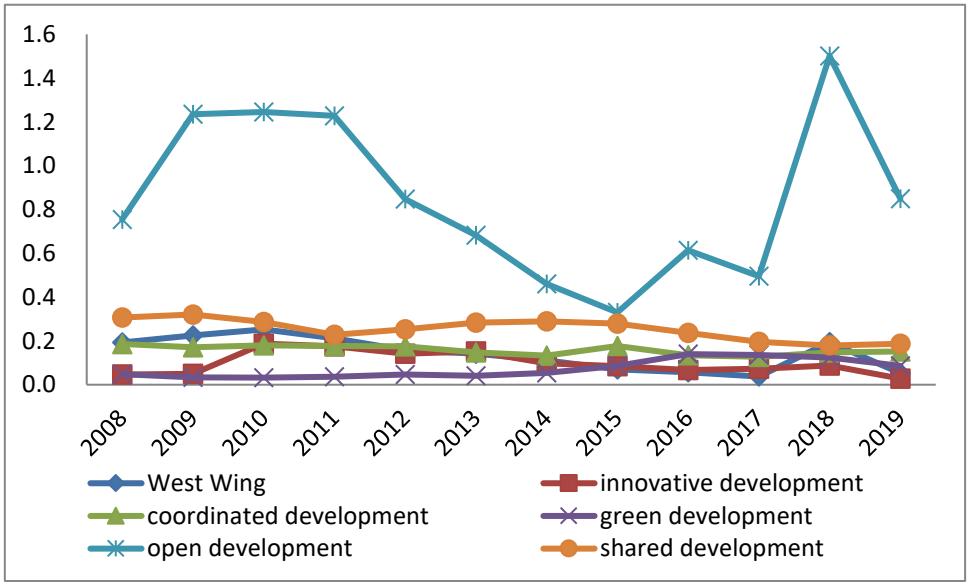

Figure A6. σ convergences of the five dimensions of quality of economic growth of the West Wing.

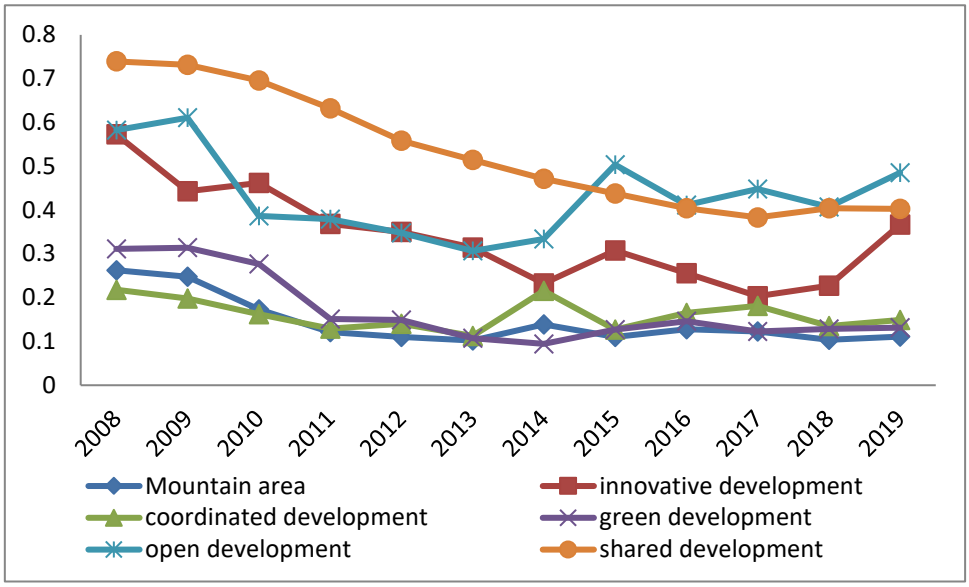

Figure A7. σ convergences of the five dimensions of quality of economic growth of the mountain area.

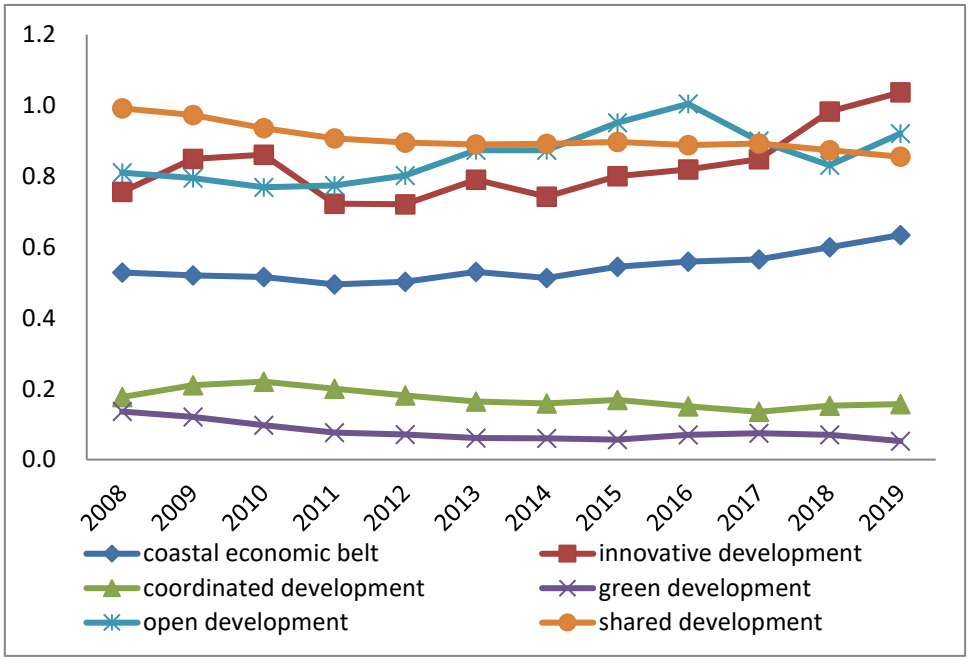

Figure A8. σ convergences of the five dimensions of quality of economic growth of the coastal economic belt.

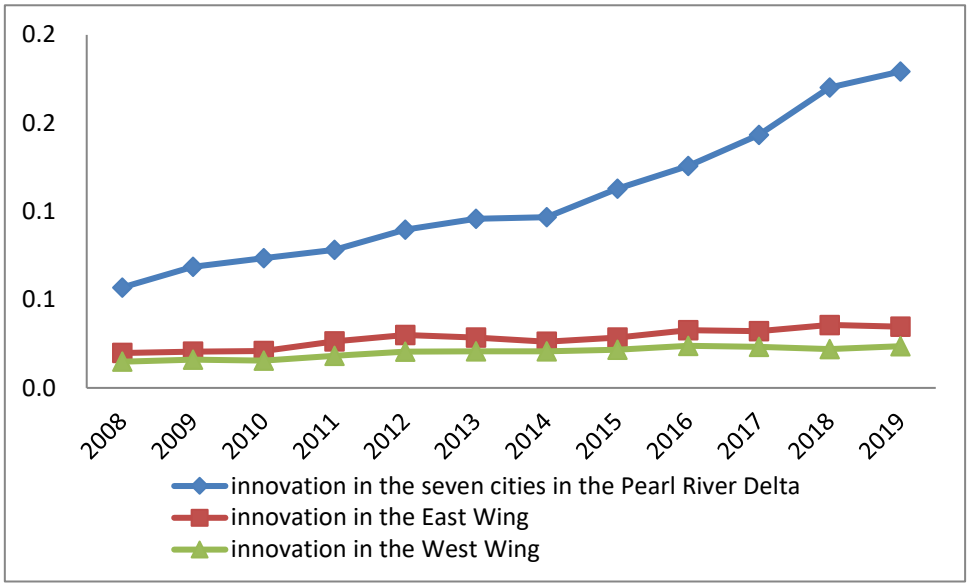

Figure A9. Innovation gap between the seven coastal cities in the Pearl River Delta and the East and West Wings.

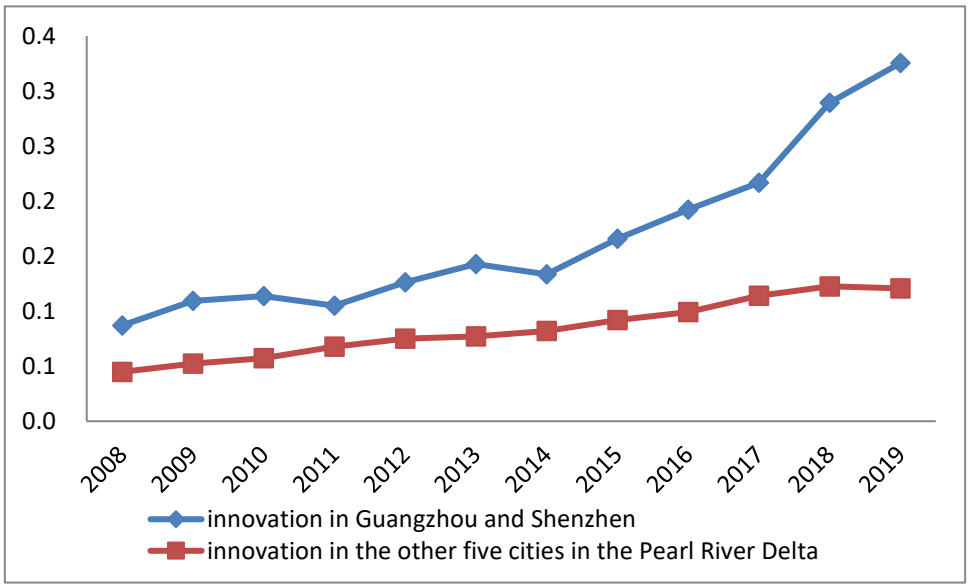

Figure A10. Innovation gap between Guangzhou, Shenzhen and the other five coastal cities in the Pearl River Delta.

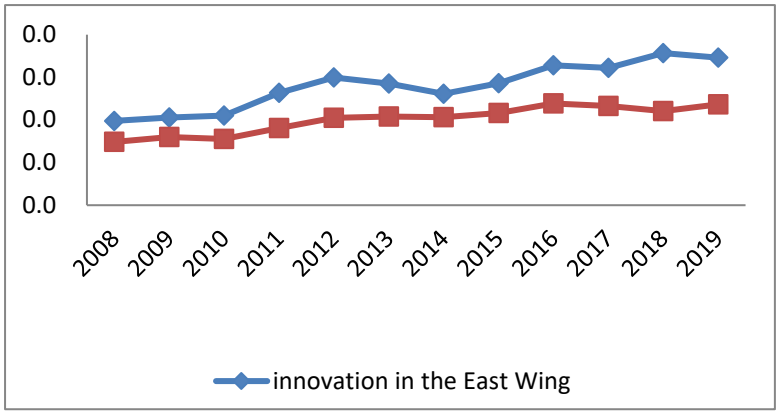

Figure A11. Innovation gap between the East Wing and the West Wing.

Table A1. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of Guangdong Province).

Variables	Guangdong Province	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.1745***	-0.1539***	-0.3196***	-0.2329***	-0.2114***	-0.2170***
	(-4.3876)	(-4.5696)	(-8.3474)	(-7.3841)	(-4.6537)	(-14.7338)
Constants	-0.2663***	-0.4330***	-0.8663***	-0.9114***	-0.8870***	-0.7071***
	(-4.1426)	(-3.9510)	(-8.1408)	(-7.1782)	(-5.3113)	(-13.3941)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0889	0.1399	0.0544	0.0195	0.2260	0.1868
sigma_e	0.0539	0.1318	0.0612	0.0622	0.3260	0.0673
R^2	0.0843	0.0908	0.2500	0.2069	0.0939	0.5095
N	231	231	231	231	231	231

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A2. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of the Pearl River Delta).

Variables	Pearl River Delta	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	0.0107	-0.0598*	-0.2292***	-0.2511***	-0.0089	-0.1262***
	(0.2027)	(-1.7876)	(-5.3152)	(-5.3896)	(-0.2210)	(-5.0324)
Constants	0.0307	-0.0554	-0.6278***	-0.9744***	-0.1173	-0.2938***
	(0.5089)	(-0.6505)	(-5.1436)	(-5.3075)	(-1.0428)	(-4.5587)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0189	0.0485	0.0334	0.0131	0.0526	0.0648
sigma_e	0.0459	0.1044	0.0383	0.0245	0.1468	0.0355
R^2	0.0005	0.0347	0.2410	0.2461	0.0005	0.2215
N	99	99	99	99	99	99

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A3. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of the East Wing).

Variables	East Wing	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.3177***	-0.3258***	-0.3167***	-0.2138***	-0.0484	-0.2575***
	(-3.0155)	(-3.1007)	(-4.4393)	(-5.0191)	(-0.6290)	(-11.2578)
Constants	-0.5972***	-1.1375***	-0.8423***	-0.8278***	-0.3302	-1.0162***
	(-2.9565)	(-2.9681)	(-4.3558)	(-4.8397)	(-1.0599)	(-10.0187)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0328	0.0842	0.0493	0.0053	0.0228	0.0429
sigma_e	0.0416	0.1568	0.0272	0.0329	0.2637	0.0673
R^2	0.1891	0.1978	0.3357	0.3924	0.0100	0.7647
N	44	44	44	44	44	44

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A4. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of the West Wing).

Variables	West Wing	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.2269**	-0.3010***	-0.1706**	-0.3382***	-0.7793***	-0.1987***
	(-2.2221)	(-2.7719)	(-2.7374)	(-2.8374)	(-4.1944)	(-4.2849)
Constants	-0.4514**	-1.1439**	-0.4770**	-1.3220***	-4.1057***	-0.6946***
	(-2.1130)	(-2.6701)	(-2.5937)	(-2.8090)	(-4.2913)	(-3.9068)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0192	0.0238	0.0300	0.0268	0.8482	0.0425
sigma_e	0.0695	0.1120	0.0436	0.0430	0.6164	0.0677
R^2	0.1455	0.2094	0.2053	0.2173	0.3776	0.3877
N	33	33	33	33	33	33

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A5. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of the mountain area).

Variables	Mountain area	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.3773***	-0.3214***	-0.4474***	-0.2304***	-0.1048**	-0.2009***
	(-4.4361)	(-3.2295)	(-4.5658)	(-3.3772)	(-2.0520)	(-5.7055)
Constants	-0.7226***	-1.1767***	-1.1556***	-0.9245***	-0.5669***	-0.8200***
	(-4.3814)	(-3.1150)	(-4.4656)	(-3.2038)	(-2.7146)	(-5.0883)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0420	0.0789	0.0539	0.0207	0.0396	0.0789
sigma_e	0.0578	0.1498	0.1042	0.1157	0.2012	0.1001
R^2	0.2865	0.1755	0.2985	0.1888	0.0791	0.3992
N	55	55	55	55	55	55

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A6. Estimated results of absolute β convergence model of quality of economic growth (of the five dimensions of the coastal economic belt).

Variables	Coastal economic belt	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.1202**	-0.1447***	-0.2278***	-0.2316***	-0.3411***	-0.2286***
	(-2.5908)	(-3.8652)	(-6.8822)	(-7.1835)	(-5.0351)	(-13.9911)
Constants	-0.1647**	-0.3751***	-0.6193***	-0.8991***	-1.3186***	-0.6950***
	(-2.3176)	(-3.2207)	(-6.6534)	(-7.0374)	(-5.4158)	(-12.8137)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0679	0.1406	0.0370	0.0120	0.4151	0.1869
sigma_e	0.0507	0.1293	0.0369	0.0307	0.3579	0.0565
R^2	0.0461	0.0970	0.2541	0.2707	0.1543	0.5848
N	154	154	154	154	154	154

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A7. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of Guangdong Province).

Variables	Guangdong Province	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.2436***	-0.3384***	-0.4740***	-0.3302***	-0.5023***	-0.3051***
	(-5.1577)	(-6.1530)	(-8.7327)	(-7.4553)	(-7.9999)	(-13.3076)
ln*PFE*	0.0219***	0.1166***	0.0440***	0.0349***	-0.3650***	0.0663***
	(2.6258)	(4.1540)	(3.8933)	(3.0686)	(-6.2114)	(4.8526)
Constants	-0.4975***	-1.6683***	-1.5361***	-1.4937***	0.0471	-1.3841***
	(-4.5851)	(-5.2870)	(-7.6615)	(-6.5815)	(0.2191)	(-9.3360)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.1082	0.2079	0.1015	0.0303	0.6955	0.2431
sigma_e	0.0532	0.1270	0.0592	0.0609	0.3002	0.0639
r2_w	0.1137	0.1605	0.3010	0.2413	0.2357	0.5594
N	231	231	231	231	231	231
Convergence rate	0.0254	0.0376	0.0584	0.0364	0.0634	0.0331

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A8. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of the Pearl River Delta).

Variables	Pearl River Delta	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.0694	-0.2971***	-0.4331***	-0.5385***	-0.0652	-0.2098***
	(-1.0082)	(-3.5375)	(-4.8539)	(-6.9107)	(-1.0868)	(-5.2699)
ln*PFE*	0.0227*	0.1706***	0.0436**	0.0383***	-0.0588	0.0317***
	(1.7799)	(3.0559)	(2.5867)	(4.3971)	(-1.2639)	(2.6485)
Constants	-0.1975	-1.6853***	-1.4677***	-2.3381***	0.0815	-0.6996***
	(-1.3974)	(-3.1236)	(-4.2471)	(-6.6362)	(0.4221)	(-4.2287)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0250	0.0910	0.0886	0.0146	0.0955	0.0966
sigma_e	0.0453	0.0998	0.0371	0.0223	0.1463	0.0343
R^2	0.0352	0.1273	0.2946	0.3819	0.0184	0.2790
N	99	99	99	99	99	99
Convergence rate		0.0320	0.0516	0.0703		0.0214

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A9. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of the East Wing).

Variables	East Wing	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.2963**	-0.7835***	-0.3432***	-0.3366***	-0.7307***	-0.3587***
	(-2.5859)	(-4.5828)	(-3.4461)	(-3.5979)	(-5.1721)	(-8.7568)
ln*PFE*	-0.0065	0.2317***	0.0042	0.0301	-0.7279***	0.0980***
	(-0.5041)	(3.2111)	(0.3864)	(1.4694)	(-5.3161)	(2.8763)
Constants	-0.5247**	-3.9314***	-0.9345***	-1.4676***	0.4750	-1.9395***
	(-2.1022)	(-4.2013)	(-3.0298)	(-3.1434)	(1.6791)	(-5.8026)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0307	0.1624	0.0541	0.0071	0.3033	0.0865
sigma_e	0.0420	0.1409	0.0276	0.0325	0.2023	0.0618
R^2	0.1945	0.3690	0.3383	0.4251	0.4323	0.8068
N	44	44	44	44	44	44
Convergence rate	0.0319	0.1391	0.0382	0.0373	0.1193	0.0404

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A10. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of the West Wing).

Variables	West Wing	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.5144**	-0.8149***	-0.4438***	-0.3857**	-0.8672***	-0.1544
	(-2.5889)	(-4.8703)	(-2.8907)	(-2.6611)	(-4.4591)	(-1.4413)
ln*PFE*	0.0758	0.2121***	0.0697*	0.0104	-0.2923	-0.0242
	(1.6693)	(3.6584)	(1.9309)	(0.5898)	(-1.3485)	(-0.4604)
Constants	-1.4451**	-4.2697***	-1.6446**	-1.5629**	-3.0394**	-0.3996
	(-2.2926)	(-4.6078)	(-2.6117)	(-2.4918)	(-2.4689)	(-0.6006)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0916	0.1416	0.0856	0.0275	0.8703	0.0244
sigma_e	0.0674	0.0937	0.0417	0.0435	0.6079	0.0686
R^2	0.2228	0.4651	0.2987	0.2269	0.4155	0.3923
N	33	33	33	33	33	33
Convergence rate	0.0657	0.1533	0.0533	0.0443	0.1836	

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A11. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of the mountain area).

Variables	Mountain area	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.4231***	-0.4736***	-0.5659***	-0.5474***	-0.4689***	-0.3767***
	(-4.8011)	(-3.8243)	(-4.7944)	(-4.4519)	(-4.2717)	(-5.8174)
ln*PFE*	0.0251	0.0935*	0.0553*	0.1599***	-0.4019***	0.1472***
	(1.6445)	(1.9680)	(1.7277)	(3.0061)	(-3.6474)	(3.1364)
Constants	-0.9393***	-2.2291***	-1.7493***	-3.0765***	0.0021	-2.3706***
	(-4.4961)	(-3.4365)	(-4.0955)	(-4.0257)	(0.0087)	(-4.5926)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0518	0.1309	0.0769	0.0848	0.2140	0.2036
sigma_e	0.0568	0.1456	0.1022	0.1073	0.1799	0.0921
R^2	0.3246	0.2371	0.3395	0.3173	0.2790	0.5014
N	55	55	55	55	55	55
Convergence rate	0.0500	0.0583	0.0759	0.0721	0.0575	0.0430

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.

Table A12. Estimated results of conditional β convergence model of quality of economic growth (of the five dimensions of the coastal economic belt).

Variables	Coastal economic belt	Innovative development	Coordinated development	Green development (LCE)	Open development	Shared development
β	-0.2008***	-0.3802***	-0.3123***	-0.3250***	-0.6877***	-0.3056***
	(-3.1038)	(-5.4462)	(-5.3474)	(-6.6772)	(-8.0891)	(-12.6408)
ln*PFE*	0.0199*	0.1502***	0.0181*	0.0186**	-0.4166***	0.0550***
	(1.7736)	(3.9232)	(1.7501)	(2.5246)	(-5.8409)	(4.1457)
Constants	-0.3989***	-1.9408***	-0.9575***	-1.3724***	-0.2366	-1.2561***
	(-2.6647)	(-4.6856)	(-4.4699)	(-6.0854)	(-0.8251)	(-8.6773)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
sigma_u	0.0959	0.2283	0.0596	0.0128	1.0412	0.2264
sigma_e	0.0503	0.1231	0.0366	0.0301	0.3217	0.0534
r2_w	0.0673	0.1877	0.2703	0.3029	0.3219	0.6308
N	154	154	154	154	154	154
Convergence rate	0.0204	0.0435	0.0340	0.0357	0.1058	0.0332

Note: Figures in parentheses are t statistics; *, **, and *** refer to the significant level of 10%, 5%, and 1% respectively.